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IEA Task 26

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2002

SHC -TASK 26: SOLAR COMBISYSTEMS

SUBTASK C

REPORT OF THE SIMULATION, OPTIMIZATION AND ANALYSIS OF THE SOLAR COMBISYSTEMS

SYSTEM #4 DHW TANK AS A SPACE-HEATING STORAGE DEVICE

LOUISE JIVAN SHAH

Preface

The report is a part of the technical deliveries for IEA Task 26 Solar Combisystems, Subtask C. The report deals with TRNSYS simulations of one of the two Danish systems in the task work.

The Danish participation in Task 26 was financed by The Danish Energy Authority.

Content

1 General description of the solar combisystem

1.1 Main features

This system is derived from a standard solar domestic hot water system, in which the collector area has been oversized, in order to be able to deliver energy to an existing space heating system. This is made through an extra heat exchanger included in the DHW tank. The system can be used to deliver energy to an existing space heating system. Heat coming from the solar collector is delivered to a DHW tank, which acts also as a small buffer tank for space heating. The DHW storage is equipped with three internal heat exchangers: the solar one in the bottom of the tank, the auxiliary one at the top, and an intermediate included in the return pipe of the space heating loop. A three-way valve conducts the fluid coming from the space heating loop either to the heat exchanger, or directly to the auxiliary boiler.

Heat management philosophy

The controller does not manage the auxiliary part of the system. If the temperature at the collector outlet is higher than the temperature at the bottom of the tank, the pump of the solar loop works. The three-way valve is managed so as to deliver solar energy to the space heating loop, i.e. when the temperature in the middle of the tank is higher than the temperature at the return temperature from the space heating loop. When the hot water temperature is too low, auxiliary heat is delivered to the tank through the three-way valve.

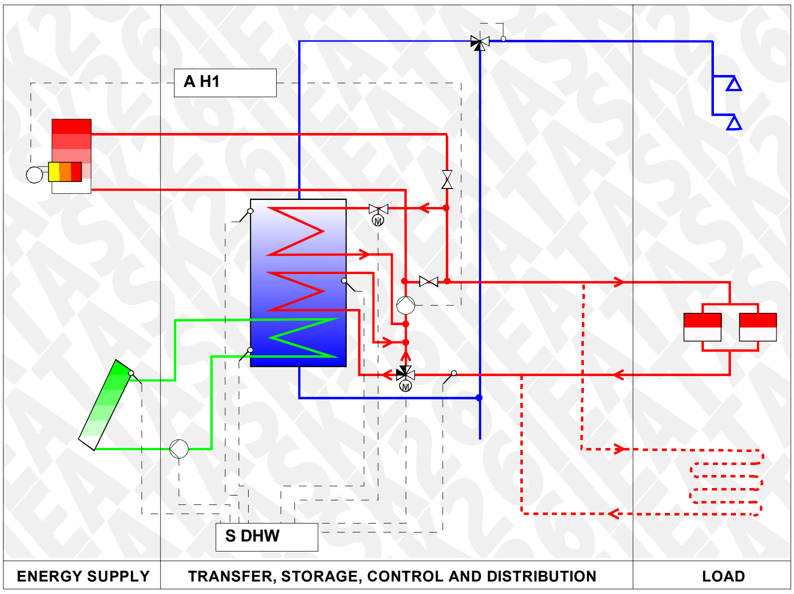


Figure 1: System design.

Specific aspects

Solar heat used for space heating is stored in the domestic hot water tank.

Influence of auxiliary energy source on system design and dimensioning

This system can work with any auxiliary energy (gas, fuel, wood, district heating). It could be also used with separate electric radiators.

Cost (range)

A typical system with 15 m² of solar collectors and an 800 litre storage unit costs about 7 000 EUR. This amount only includes the solar part (collectors, storage tank, controller and heat exchanger, installation), since the auxiliary part (boiler, radiator circuit) already exists. Total cost for complete heating system with solar is 15 600 EUR, and reference cost for complete heating system without solar is 9 300 EUR.

Market distribution
This system is quite new in Denmark. Only one company markets this system, with a total collector area in operation of 100 m². The system is marketed by the manufacturer and is available anywhere in Denmark from the nearest installer (400-800 potential installers).

Manufacturer: Batec A/S

2 Modelling of the system

2.1 TRNSYS model

The combisystem is modelled in TRNSYS 14.2 [1] and the model includes collectors, collector loop, storage, auxiliary boiler, building, radiator, pumps, and control systems. Figure 2 shows a diagram of the system model, and each component is described in greater detail in the next section.

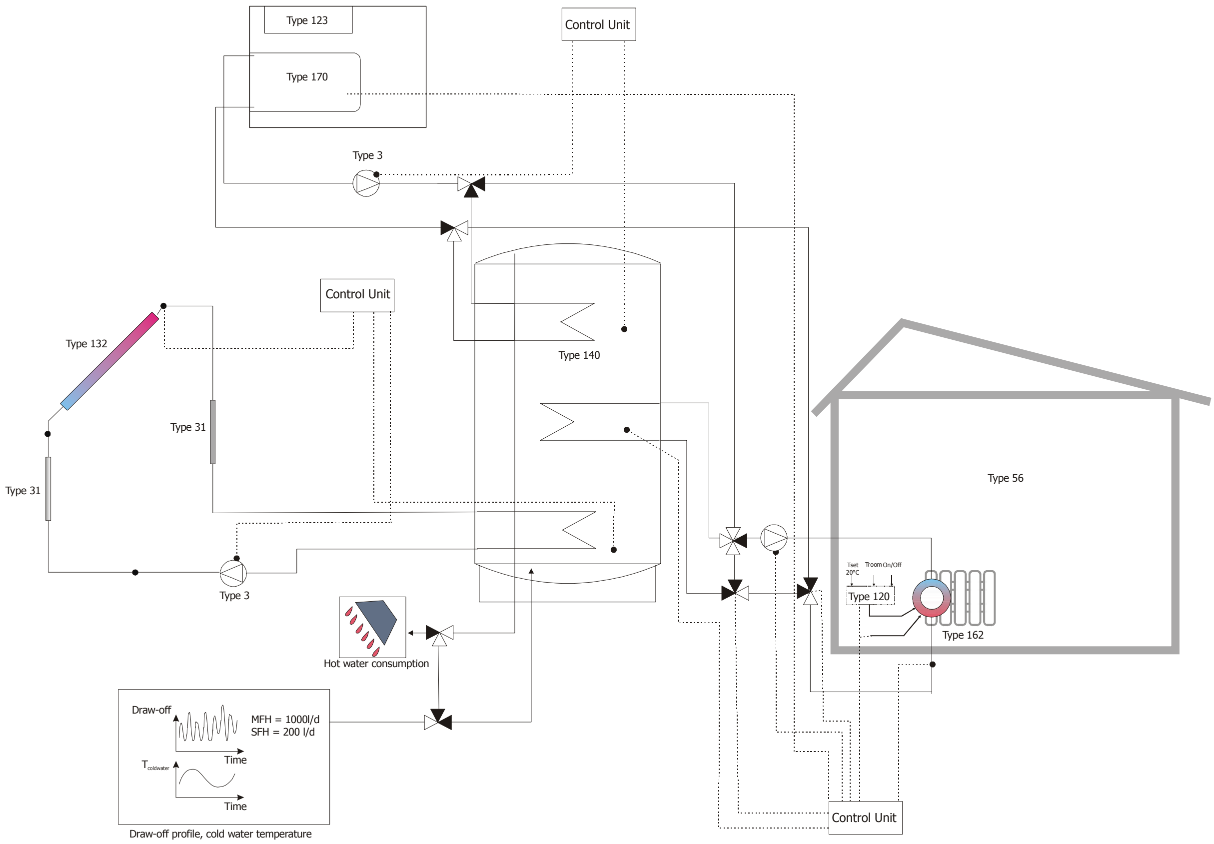


Figure 2: Diagram of System # 4 modelled in TRNSYS 14.2.

2.2 Definition of the components included in the system and standard inputs

The simulations will start out with investigations of a “base case” system with a specific collector area, tank volume, insulation thickness, heat exchanger size etc. In the following subsections, the most important model components and parameters of the base case system are described.

2.2.1 Collector

For the later comparison of different combisystem concepts, it is an advantage if all the systems are modelled with similar collectors. Therefore, the combisystem is modelled with a standard flat plate collector with a reference efficiency expression as described in Table 1. The base case system has a collector area of 15 m² and, as the system is not a low flow system, a specific mass flow rate through the collectors is 72 l/m²/h. The collector is modelled with the non-standard TRNSYS Type 132.

Collector	η_0	0.8 -
	a_1	3.5 W/m²-K
	a_2	0.015 W/m²-K²
	inc. angle modifier (50°)	0.9 -
	Area	15 m²
	Specific mass flow	72 l/m²h

Table 1: Collector data (as defined in Appendix 1: Milestone Report C0.2).

2.2.2 Pipes between Collector and Storage

The geometry and insulation thickness of the pipes between collector and tank is given in Table 2. For the heat loss calculations, an average surrounding temperature of 15 °C is given. The pipes in the collector loop are modelled with TRNSYS Type 31.

Collector loop	Length, tank to collector (cold side)	15 m
	Length, tank to collector (hot side)	15 m
	Inner diameter	0.02 m
	Outer diameter	0.022 m
	Insulation thickness	0.02 m
	Insulation thermal conductivity	0.042 W/mK
	Heat transfer media	Glycol (40%)/Water

Table 2: Collector loop data (as defined in Appendix 1: Milestone Report C0.2).

2.2.3 Storage

The base case storage tank has a total volume of 750 l. The height of the storage is defined from following equation as defined in Appendix 1: Milestone Report C0.2.

$$H=Max[Min\{2.2,1.78+0.39\cdot ln(V)\},0.8]$$

where,

H is the storage height [m]

V is the storage volume [m³]

For this storage, the equation gives a storage height of 1.67 m and thus a diameter of approximately 0.76 m.

The top and sides of the base case storage tank is insulated with 0.15 m insulation material with a thermal conductivity of 0.042 W/mK. The bottom is not insulated. As theoretical calculated heat losses are typical smaller than actual measured heat losses, a correlation constant is multiplied with the theoretical calculated heat loss [from Appendix 1: Milestone Report C0.2]:

$$UA_{real}=C_{corr}\cdot UA_{theory}$$

C_{corr}=Max[1.1,(1.5-V/10)]

where,

UA_{real} is the adjusted heat loss coefficients for the storage top/side/bottom [W/K]

C_{corr} is the correlation constant [-]

UA_{theory} is the theoretical heat loss coefficients for the storage top/side/bottom [W/K]

V is the storage volume [m³]

For this storage, the equation gives C_{corr} = 1.425.

The vertical thermal conductivity is defined from the following equation [from Appendix 1: Milestone Report C0.2]:

$\lambda_{vertical}$=Max[0.7,(1.3-V/10)]

where

$\lambda_{vertical}$ is the vertical thermal conductivity [W/mK]

V is the storage volume [m³]

For the base case storage $\lambda_{vertical}$ equals 1.225 W/mK.

As shown in Figure 1, the storage tank includes three internal heat exchangers: Heat exchanger no. 1 is used in the solar collector loop. It is a serpentine heat exchanger with a heat transfer coefficient of 750 W/K and it is placed in the lowest part of the storage tank. Heat exchanger no. 2 is used in the space heating loop. It is a serpentine heat exchanger with a heat transfer coefficient of 750 W/K and it is placed in the middle part of the storage tank. Heat exchanger no. 3 is used in the auxiliary heating loop. It is also a serpentine heat exchanger with a heat transfer coefficient of 750 W/K and it is placed in the top part of the storage tank.

The storage tank is modelled with TRNSYS Type 140 (version 1.95) [2] and the storage data are summarized in Table 3.

Storage tank	Total volume	0.75 m³
	Height	1.67 m
	Diameter	0.76 m
	Auxiliary volume	0.15 m³
	Insulation thickness, top	0.15 m
	Insulation thickness, sides	0.15 m
	Insulation thickness, bottom	0 m
	Thermal conductivity of insulation material	0.042 W/mK
	Vertical thermal conductivity	1.225 W/mK
	Solar HX inlet [1)]	0.3
	Solar HX outlet [1)]	0.05
	Space heating HX inlet [1)]	0.4
	Space heating HX outlet [1)]	0.7
	Auxiliary HX inlet [1)]	0.8
	Auxiliary HX outlet [1)]	1
	Solar HX heat transfer capacity	750 W/K
	Space heating HX heat transfer capacity	750 W/K
	Auxiliary HX heat transfer capacity	750 W/K
	Cold water inlet [1)]	0
	Hot water outlet [1)]	1

	Position of collector control temperature sensor [1)]	0.02
	Position of space heating control temperature sensor [1)]	0.4
	Number of nodes	30
	Charging and discharging	Non-stratified

Table 3: Storage tank data. [1)]Relative height: Storage bottom = 0, Storage top = 1.

2.2.4 Burner

The burner in the system is a modulating condensing gas burner. The burner has a nominal power of 15 kW and modulates in the range of 25%-100%. For the heat loss calculations, a surrounding temperature of 15 °C is used.

The gas burner is modelled with TRNSYS non-standard Type 170 (version 3.00) [3] and it is controlled with TRNSYS non-standard Type 123. The burner data are summarized in Table 4.

Burner	Nominal power	15 kW
	Set supply temperature for domestic hot water	65°C
	Fuel type[2)]	Natural gas, high
	Ambient temperature in the boiler house	15°C
	Operation standby temperature of the boiler	30°C
	Hysteresis temperature difference for standby temperature	5 K
	Maximum main water temperature of the boiler	90°C
	Air surplus number (λ) [2)]	1.2
	Modulation range	25%-100%
	Mass of the boiler water	7.5 kg
	Temperature difference between flue gas and return temperature in the heat exchanger[2)]	10 K
	Maximum losses through radiation related to the maximum heat performance[2)]	3.5 %
	Standby losses related to the maximum heat performance[2)]	1.5 %
	Mode[2)]	10
	Minimum running time	1 min
	Minimum stand still time	1 min

Table 4: Burner data as defined in Appendix 1: Milestone Report C0.2 or in agreement with Task 26. [2)] See [3] for details.

2.2.5 Building

The combisystem will be modelled together with a full single-family house with either a low, a medium, or a high space heating demand. The three houses have the same geometry but different building physics data were defined in a way that the specific yearly space heat demand for Zurich climate amounts to 30, 60 and 100 kWh/m² per year.

The building is modelled with TRNSYS type 56 and an overview of the building properties is given in Table 5.

Building	Specific space heating demand for Zurich climate	**30 kWh/m² per year**
	Area	140 m²
	Total window area (East: 4m², West: 4m², North: 3m², South: 12m²)	23 m²
	Window U-value	0.4 W/m²K
	Window g-value	0.408
	External walls, U-value	0.135 W/m²K
	Roof, U-value	0.107 W/m²K
	Ground floor, U-value	0.118 W/m²K
Building	Specific space heating demand for Zurich climate	**60 kWh/m² per year**
	Area	140 m²
	Total window area (East: 4m², West: 4m², North: 3m², South: 12m²)	23 m²
	Window U-value	1.4 W/m²K
	Window g-value	0.589
	External walls, U-value	0.342 W/m²K
	Roof, U-value	0.227 W/m²K
	Ground floor, U-value	0.196 W/m²K
Building	Specific space heating demand for Zurich climate	**100 kWh/m² per year**
	Area	140 m²
	Total window area (East: 4m², West: 4m², North: 3m², South: 12m²)	23 m²
	Window U-value	2.8 W/m²K
	Window g-value	0.755
	External walls, U-value	0.508 W/m²K
	Roof, U-value	0.494 W/m²K
	Ground floor, U-value	0.546 W/m²K

Table 5: Building properties as defined in Appendix 1: Milestone Report C0.2.

2.2.6 Heat distribution

The space heat distribution system is defined as an ambient temperature controlled radiator system with thermostatic valves adjusting the mass flow according to variable inner heat loads.

The radiator is modelled with TRNSYS non-standard Type 162 and it is controlled with a PID-controller, TRNSYS non-standard Type 120. Table 6 lists the design temperatures and the nominal power for the radiator system for the different buildings and climates.

Climate	Building	Nom. power [W]	Design forward temperature [°C]	Design return temperature [°C]	Design ambient temperature [°C]
Stockholm	30 kWh/m²/year	3480	35	30	-17
Stockholm	60 kWh/m²/year	6160	40	35	-17
Stockholm	100 kWh/m²/year	9050	60	50	-17
Zurich	30 kWh/m²/year	2830	35	30	-10

Zurich	60 kWh/m²/year	4950	40	35	-10
Zurich	100 kWh/m²/year	7290	60	50	-10
Carpentras	30 kWh/m²/year	2460	35	30	-6
Carpentras	60 kWh/m²/year	4260	40	35	-6
Carpentras	100 kWh/m²/year	6320	60	60	-6

Table 6: Radiator data (from Appendix 1: Milestone Report C0.2).

2.2.7 Control strategy

There are four controllers in the system: One for the collector loop, one for the space heating system, one for setting the domestic hot water priority and one for setting the minimum running time and standstill time of the burner. Table 7 describes the different controllers:

Collector control	Model (on/off controller)	Type 2
	Start temperature difference	10 K
	Stop temperature difference	2 K
Space heating control	Model (PID controller)	Type 120
	Width of PID-band	3 K
	Proportional gain in PID-band	0.8
	Integral gain in PID-band	0.05
	Differential gain	0
DHW priority control	Model (on/off controller)	Type 2
	Set temperature of hot water	50.5°C
	Hysteresis	+- 5 K
Burner running time control	Model	Type 123
	Minimum running time	1 min
	Minimum stand still time	1 min

Table 7: Burner data as defined Appendix 1: Milestone Report C0.2 or in agreement with Task 26.

2.3 Validation of the system model

Since only very few systems have been installed and none have been measured, the simulation model has not been validated against measurements.

3 Simulations for testing the library and the accuracy

TRNSYS is an open source code where the user can modify sub-models and compile them into a user specific dynamic link library called TRNLIB.DLL. In the Task 26 subtask C work, all users from all countries had to use similar TRNLIB.DLL in order to be able to compare the results. Therefore, a TRNLIB.DLL comparison with a reference DLL file had to be performed. This comparison is described in the following section.

3.1 Result of the TRNLIB.DLL check

The local TRNLIB.DLL was checked by calculating the three single family reference buildings for all three climates. The three tables below show the results calculated with the reference TRNLIB.DLL (top table), the results calculated with the local TRNLIB.DLL (middle table) and the differences in percents (bottom table).

In the table, Q_{SH} is the space heating demand, Q_{DHW} is the energy demand for domestic hot water, Q_{BURNER} is the gross energy consumption of the natural gas, $Q_{REF,PRI}$ is the primary energy consumption (=gross gas consumption + gross electrical energy consumption) and Q_{pen} is the penalty (see Appendix 2: Milestone Report C3.1 for details).

From the tables it is clear that the local TRNLIB.DLL calculate the expected results for the single family houses. Thus, the local TRNLIB.DLL is used for the calculations.

Results - Reference Buildings

Thomas Letz, October 16, 2001 - Richard Heimrath, April 21, 2002

	QSH / kWh			QDHW / kWh	QBURNER / kWh			QREF,PRI / kWh			Qpen / kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	1565	3587	6925	2723	5802	8180	12107	6738	9342	13521	27338	31807	28129
Zürich	4319	8569	14283	3040	9414	14415	21137	10802	15909	22743	7101	6208	3766
Stockholm	6264	12227	19773	3122	11800	18784	27693	13313	20438	29444	6247	5091	2453

Results - Reference Buildings

Louise Jivan Shah, August 19, 2002

	QSH / kWh			QDHW / kWh	QBURNER / kWh			QREF,PRI / kWh			Qpen / kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	1568	3590	6922	2723	5805	8184	12100	6741	9341	13520	27610	32140	28460
Zürich	4314	8563	14270	3040	9409	14410	21120	10800	15900	22730	7214	6326	3849
Stockholm	6260	12190	19760	3122	11790	18780	27680	13310	20430	29430	6350	5195	2518

Difference

Louise Jivan Shah, August 19, 2002

	QSH / kWh			QDHW / kWh	QBURNER / kWh			QREF,PRI / kWh			Qpen / kWh		
	SFH 30	SFH 60	SFH 100	SFH	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100	SFH 30	SFH 60	SFH 100
Carpentras	-0.19%	-0.08%	0.04%	0.00%	-0.05%	-0.05%	0.06%	-0.04%	0.01%	0.01%	-0.99%	-1.05%	-1.18%
Zürich	0.12%	0.07%	0.09%	0.00%	0.05%	0.03%	0.08%	0.02%	0.06%	0.06%	-1.59%	-1.90%	-2.20%
Stockholm	0.06%	0.30%	0.07%	0.00%	0.08%	0.02%	0.05%	0.02%	0.04%	0.05%	-1.65%	-2.04%	-2.65%

Table 8: Top table: *Reference building results calculated with the reference TRNLIB.DLL.* Middle table: *Reference building results calculated with the local TRNLIB.DLL.* Bottom table: *The differences in percents.*

3.2 Results of the accuracy and the time step check

It was decided in the task work that the minimum running time and standstill time for the gas burner should be 1 minute. Therefore, the maximum time step can be only 1 minute and this value is kept for all simulations. The accuracy of the simulations was investigated by varying the convergence and integral tolerances from 0.5 to 0.0005.

Table 9 shows the results of the accuracy check. In the table, ε is defined as:

$$\varepsilon = \frac{F_{save,therm}(i) - F_{save,therm}(i-1)}{F_{save,therm}(i-1)} \cdot 100\% \qquad with$$

$$f_{sav,therm} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}}} = 1 - \frac{gross\ gas\ consumption\ with\ the\ solar\ heating\ system}{gross\ gas\ consumption\ without\ the\ solar\ heating\ system}$$

where *i* is the run number defined in the table. It was decided in the task work that ε should be less than 0.01.

Further, the energy imbalance, EI, is defined as:

$$\begin{aligned} EI = &\ Energy\ into\ system\ \div\ Energy\ out\ of\ system \\ = &\ Energy\ supplied\ from\ gas\ boiler\ to\ heating\ media \\ &+ Energy\ supplied\ from\ collector\ loop\ to\ storage\ tank \\ &\div Space\ heating\ consumption \\ &\div DHW\ \ consumption \\ &\div Heat\ loss\ from\ storage \end{aligned}$$

In addition, the relative energy imbalance, REI, is defined as:.

$$EI = \frac{EI}{Energy\ into\ system} \cdot 100\%$$

i [run no.]	Convergence Tolerance [-]	Integral Tolerance [-]	Time Step [h]	$F_{save,therm}$ [%]	ε [%]	Energy imbalance [kWh]	Relative energy imbalance [%]
1	0.05	0.05	1/60	23.1	-	755	5.42
2	0.01	0.01	1/60	29.9	29.43	138	1.03
3	0.005	0.005	1/60	30.6	2.32	67	0.50
4	0.001	0.001	1/60	31.3	2.20	21	0.16
5 crashed	0.0005	0.0005	-	-	-	-	-

Table 9: Influence of the TRNSYS convergence and integral tolerances.

It can be seen in the table that ε does not meet the demands. However, the low energy imbalance for run number 4 indicates that the accuracy for this tolerance is sufficient.

4 Sensitivity Analysis and Optimization

4.1 Presentation of results

In this section, a sensitivity analysis of the combisystem is performed. The sensitivity analysis is performed for Zurich climate and for the building with the 60 kWh/m²/year heating demand.

The influence of the different systems parameters is evaluated by two fractional energy savings and a fractional savings indicator:

Fractional thermal energy savings:

$$f_{sav,therm} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}}}$$

Extended fractional energy savings:

$$f_{sav,ext} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}} + \dfrac{W_{solar}}{\eta_{el}}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}} + \dfrac{W_{ref}}{\eta_{el}}}$$

Fractional savings indicator:

$$f_{si} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}} + \dfrac{W_{solar}}{\eta_{el}} + Q_{penalty,solar,red}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}} + \dfrac{W_{ref}}{\eta_{el}}}$$

where

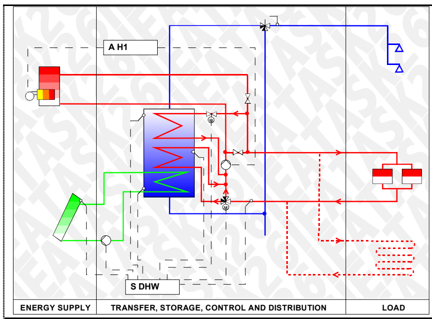
$\dfrac{Q_{burner,solar}}{\eta_{burner,solar}}$	is the gross gas consumption with the solar heating system	[kWh]
$\dfrac{Q_{burner,ref}}{\eta_{burner,ref}}$	is the gross gas consumption without the solar heating system	[kWh]
$\dfrac{W_{solar}}{\eta_{el}}$	is the gross electrical energy consumption with the solar heating system	[kWh]
$\dfrac{W_{ref}}{\eta_{el}}$	is the gross electrical energy consumption without the solar heating system	[kWh]

$Q_{penalty,solar,red}$ is an extra penalty for overheating the house and for too low domestic hot water temperatures. All definitions are detailed described in Appendix 2: Milestone Report C3.1.

4.1.1 Sensitivity analysis

A quick overview of the base case parameters is given in Table 10 and in Table 11 a summary of the investigated parameters including their influence on the system performance is given.

Figure 3 Figure 20 show the results for each parameter analysis and the results are if necessary commented below the figures.



#4 DHW TANK AS A SPACE-HEATING STORAGE DEVICE			
Main parameters (Base Case):			
Building:	*SFH 60 kWh/m²a*	Storage Volume:	*0.75 m³*
Climate:	*Zurich*	Storage height	*1.67 m*
Collectors area:	*15 m²*	Thermal insulation, Top	*15 cm*
Collector type:	*Standard Flat Plate*	Thermal insulation, Side	*15 cm*
Specific flow rate (Collector)	*72 kg/m²-h*	Thermal insulation, Bottom	*0 cm*
Collector azimuth/tilt angle	*0 / 45°*	Nominal auxiliary heating rate	*15 kW*
Collector upper/lower dead band	*10K / 2K*	Heat Exchanger:	*750 W/K*
Solar HX inlet [1)]	0.3	Solar HX outlet [1)]	0.05
Space heating HX inlet [1)]	0.4	Space heating HX outlet [1)]	0.7
Auxiliary HX inlet [1)]	0.8	Auxiliary HX outlet [1)]	1
Simulation parameter:		Storage nodes	*30*
Time step	*1/60 h*	Tolerances Integration Convergence	*0.001 / 0.001*

Table 10: Main parameters for the base case system.

Summary of Sensitivity Parameters		
Parameter	Variation	[1]Variation in $f_{sav,ext}$
Base Case	-	24.9%
Collector size [m^2] (fixed store size (0.75 m^3)	5 – 25	16.4 – 26.8%
Collector Size [m^2] (fixed store spec. vol. 0.05 m^3/m^2)	5 – 25	14.3 – 29.3%
Store Size [m^3] (fixed collector area of 15 m^2)	0.5 – 1.250	18.6 – 25.8%
Collector Azimuth [°] (fixed tilt of 60°)	-90 – 90	19.1 – 24.9%
Collector Tilt [°] (fixed azimuth of 0°)	0 – 75	19.8 – 25.2%
[2]Boiler Outlet Rel. Height [-]	0.5 – 0.9	22.0 – 25.9%
Auxiliary Heat Exchanger UA [%] (variation from BC value)	50 – +200	25.0 – 25.2%
Collector Heat Exchanger UA [%] (variation from BC value)	50 - +200	23.9 – 25.6%
Space Heating Heat Exchanger UA [%] (variation from BC value)	50 - +200	24.7 – 25.1%
[3]Store Insulation: top [cm]	5 – 25	24.6 – 25.1%
[3]Store Insulation: sides [cm]	5 – 25	23.8 – 25.5%
[3]Store Insulation: bottom [cm]	0 – 25	22.9 – 25.7%
[3]Store Insulation: whole store [cm]	5 – 25	21.5 – 26.4%
Collector Controller dT_{start} [K] (dTstop = 2 K)	5 – 30	24.7 – 25.2%
DHW set temperature [°C]	40 – 60	23.9 – 26.7%
Collector Controller Sensor Rel. Height [-]	0.02 – 0.3	24.9 – 26.5%
Space heating Controller Sensor Rel. Height [-]	0.4 – 0.7	24.7 – 24.9%
Climate (60 kWh SFH – Base Case)	Carp. / Zur. / Stock.	43.7% / 24.9% / 21.9%
Burner switched off during summertime		25.6%

Table 11: Summary of the sensitivity analysis.

[1] The variation in fractional savings indicated in the table does not represent the values for the extremes of the range, rather the minimum and maximum values for the range indicated.

[2] The thermostat settings for store charging and electrical heater were NOT changed for these variations. Adjusting the setting to just meet the demand of the period with the highest load would probably lead to different results.

[3] The insulation has a conductivity of 0.042 W/m-K and has a correction factor for "imperfection" of C_{corr}=Max[1.1,(1.5-V/10)].

Sensitivity parameter:	Collector size [m^2] (fixed store size 0.75 m^3)	5 – 25 m^2

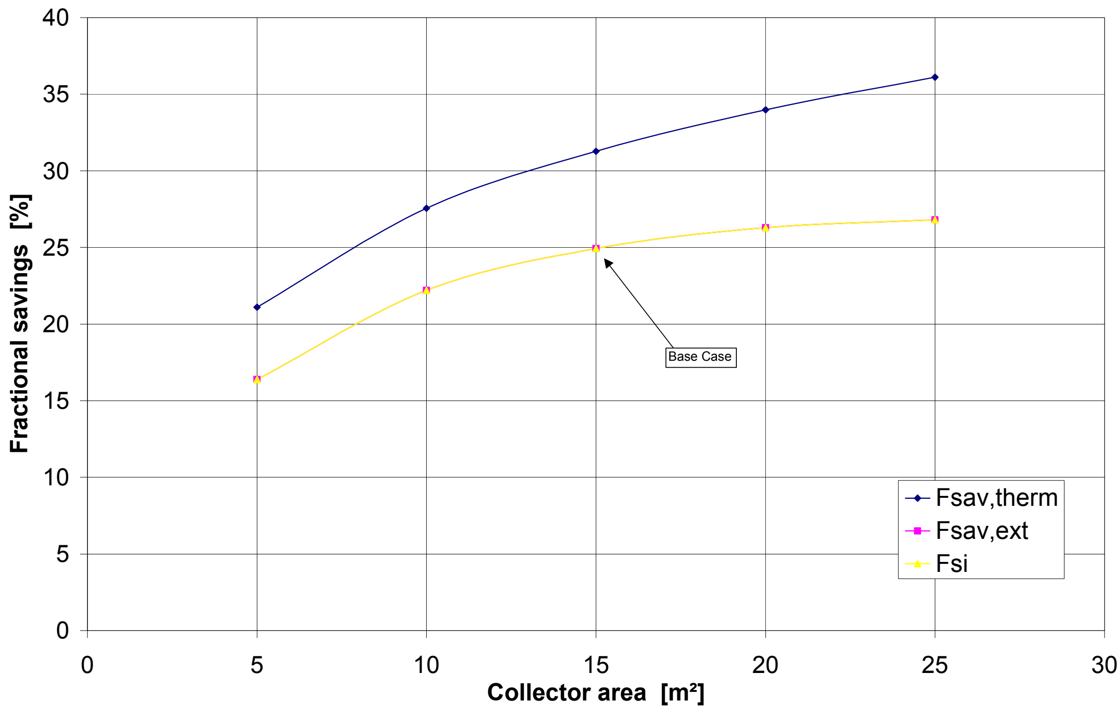


Figure 3. Variation of fractional energy savings with collector size with fixed store volume of 0.75 m^3.

Differences from Base Case

The collector heat exchanger UA-value and the space heating heat exchanger UA-value are varied with the collector area in the following way:

$$UA_{HX} = A_{collector} \cdot 50 \quad [W/K]$$

Description of Results

As expected, the fractional savings increase with increasing collector area. Further it seems that there is not much gained by having larger than 15 m² of collectors. No penalties occurred for the settings so $f_{si} = f_{sav,ext}$.

Comments

None.

Sensitivity parameter:	Collector Size [m2] (fixed spec. store vol. 0.05 m^3/m^2)	5 – 25 m^2

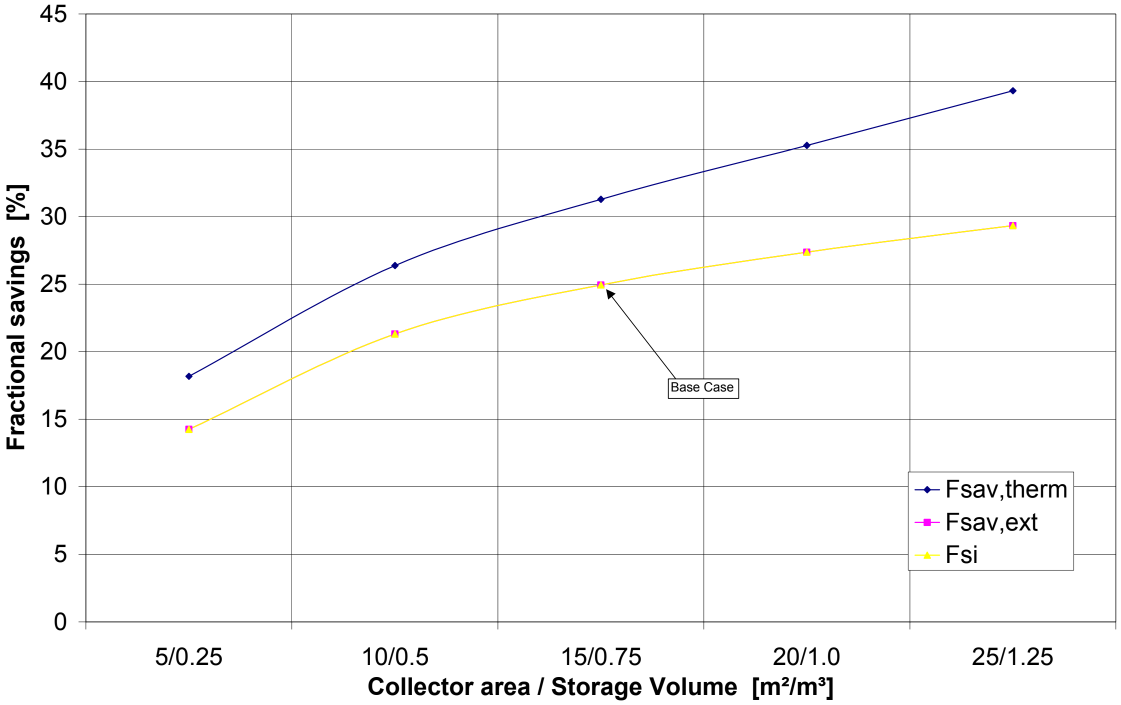


Figure 4. Variation of fractional energy savings with collector size with a fixed specific store volume of 0.05 m^3/m^2.

Differences from Base Case

- The height for the outlet of the auxiliary heat exchanger was varied so that the volume heated by the auxiliary was always the same (0.15 m^3).
- The height of the store is calculated with the following equation: H=Max[Min{2.2,1.78+0.39·ln(V)},0.8] where H is the storage height [m] and V is the storage volume [m³].
- The heat loss coefficient for the store varied using equations for the area of the relevant section. In addition, a volume sensitive "imperfection" factor, C_{corr}, was used to multiply the theoretical values: C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [m³].
- The vertical thermal conductivity is varied by the following equation: $\lambda_{vertical}$=Max[0.7,(1.3-V/10)].

Description of Results

As expected, the fractional savings increase with increasing collector area. Further, for collector areas larger than 15 m² the parasitic energy consumption increase rapidly. No penalties occurred for the settings so $f_{si} = f_{sav,ext}$.

Comments

None.

Sensitivity parameter:	Store Size [m3] (fixed collector area of 15 m^2)	0.25 – 1.25 m^3

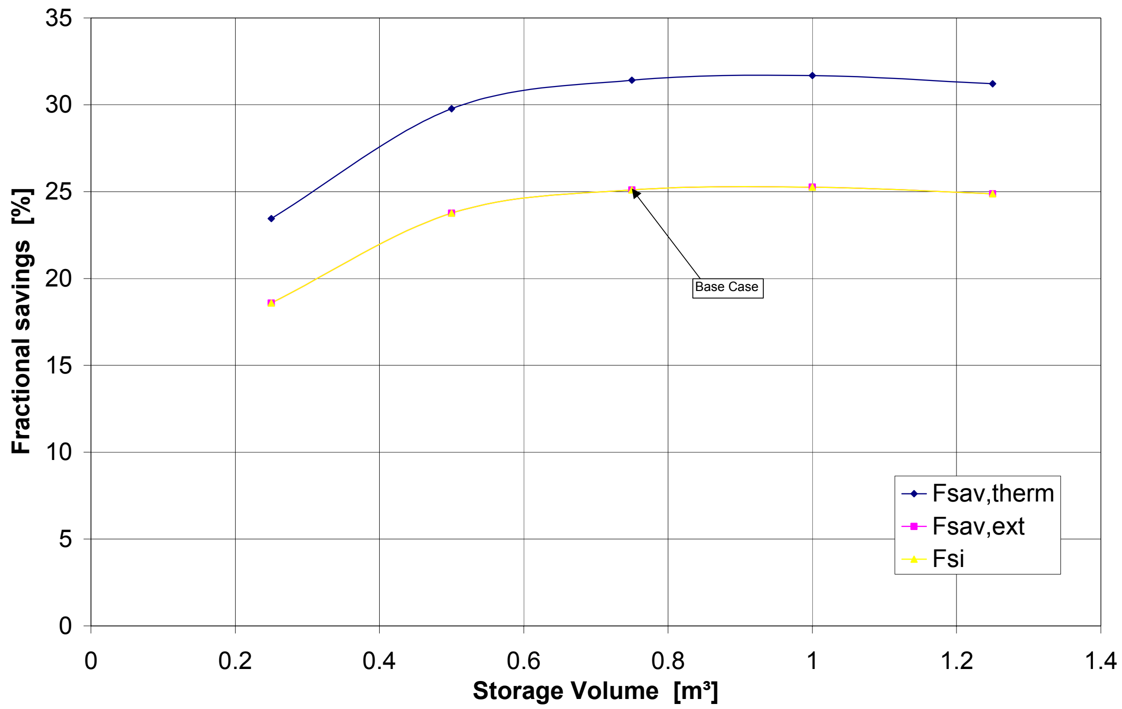


Figure 5. Variation of fractional energy savings with store volume with fixed collector area of 15 [m^2].

Differences from Base Case

- The height for the outlet of the auxiliary heat exchanger was varied so that the volume heated by the auxiliary was always the same (0.15 m^3).
- The height of the store is calculated with the following equation: H=Max[Min{2.2,1.78+0.39·ln(V)},0.8] where H is the storage height [m] and V is the storage volume [m³].
- The heat loss coefficient for the store varied using equations for the area of the relevant section. In addition, a volume sensitive "imperfection" factor, C_{corr}, was used to multiply the theoretical values: C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [m³].
- The vertical thermal conductivity is varied by the following equation: $\lambda_{vertical}$=Max[0.7,(1.3-V/10)].

Description of Results

Here the savings show an optimum storage volume at around 0.75 - 1.0 m^3, which corresponds to 0.05-0.67 m³/m² collector. Below this value, the store is too small to utilise the solar energy in the best way, especially since the volume heated by the auxiliary is always the same. Above this value the heat losses from the store start to outweigh the gain in utilised solar heat and the overall savings decrease again.

Comments

None.

Sensitivity parameter:	Collector Azimuth [°] (fixed tilt of 45°)	-90° - 90°

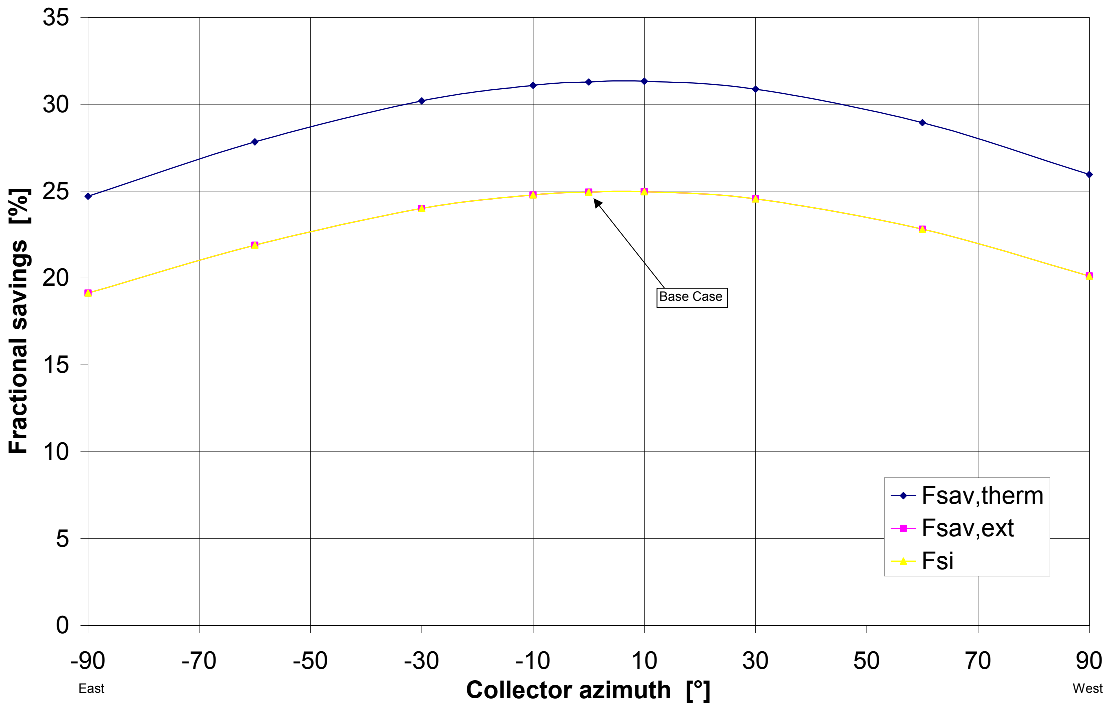


Figure 6. Variation of fractional energy savings with collector azimuth with fixed tilt angle of 45°.

Differences from Base Case
None

Description of Results
Here the savings show an optimum at around 10° west. Of course, this depends on the climate data and the consumption pattern (DHW and space heating). Generally, the ambient temperature is higher in the afternoon, which improves the collector performance. Therefore, for most climates and with a uniform consumption pattern during the day, a collector orientation slightly towards west is preferable.

Comments
None

Sensitivity parameter:	Collector Tilt [°] (fixed azimuth of 0°)	15° - 90°

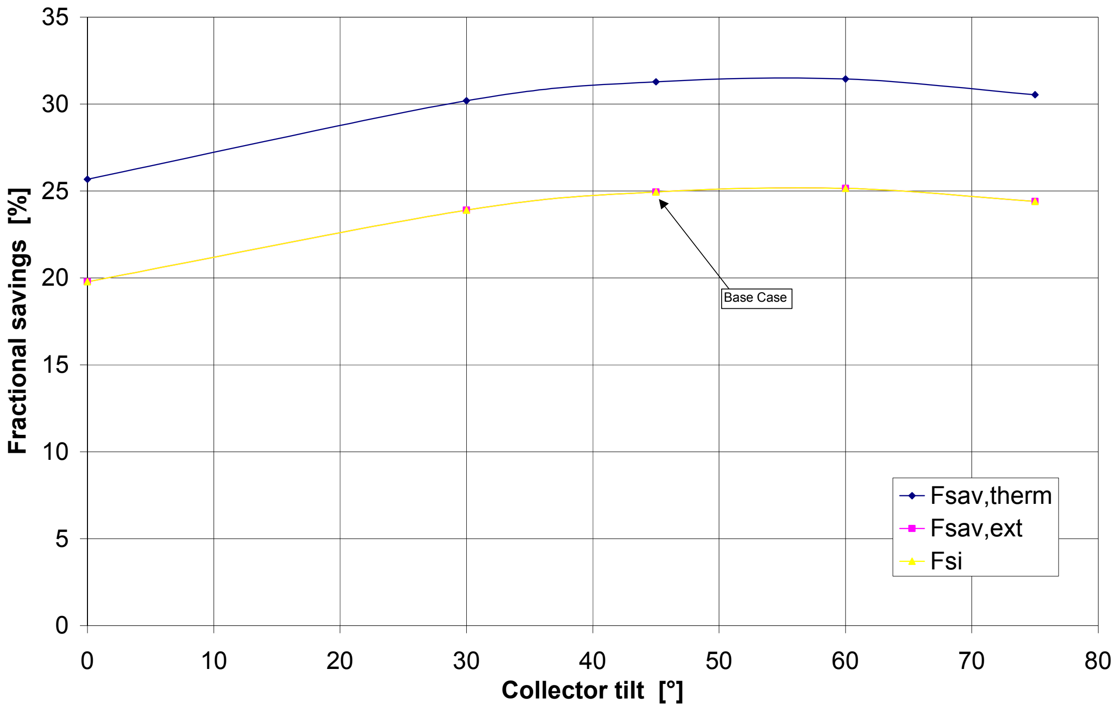


Figure 7. Variation of fractional energy savings with collector tilt, with fixed azimuth angle of 0°.

Differences from Base Case

None

Description of Results

Here the savings show an optimum at around 55° collector tilt. This is dependent on the location, climate and consumption pattern. Generally, the larger the space heating load in relation to the DHW load, the higher the optimum tilt angle.

Comments

The collector efficiency curve has not been changed due to the different tilts.

Sensitivity parameter:	Boiler Outlet Rel. Height [-]	0.5 – 0.9

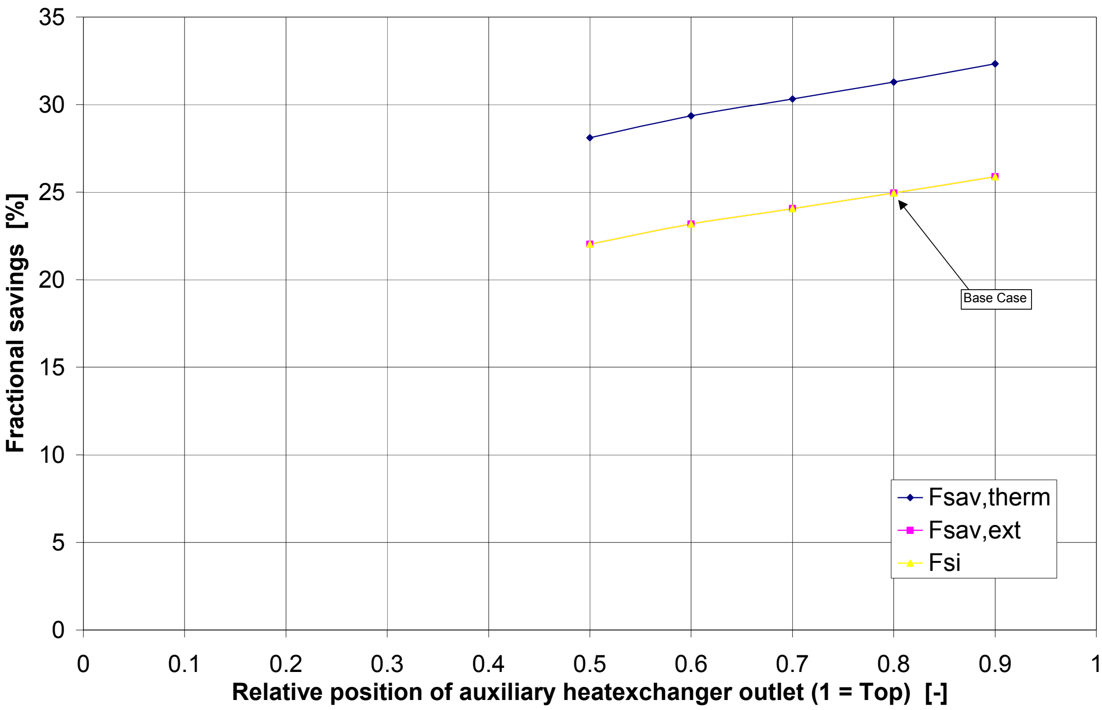


Figure 8. Variation of fractional energy savings with the auxiliary heat exchanger outlet.

Differences from Base Case
None

Description of Results
The savings increase with a smaller auxiliary volume. No penalties occurred for the settings (f_{si} = $f_{sav,ext}$) so even with an auxiliary volume of only 75 litres, the comfort is not decreased.

Comments
None

Sensitivity parameter:	Collector Heat Exchanger UA (variation from base case value)	-50% - +100%

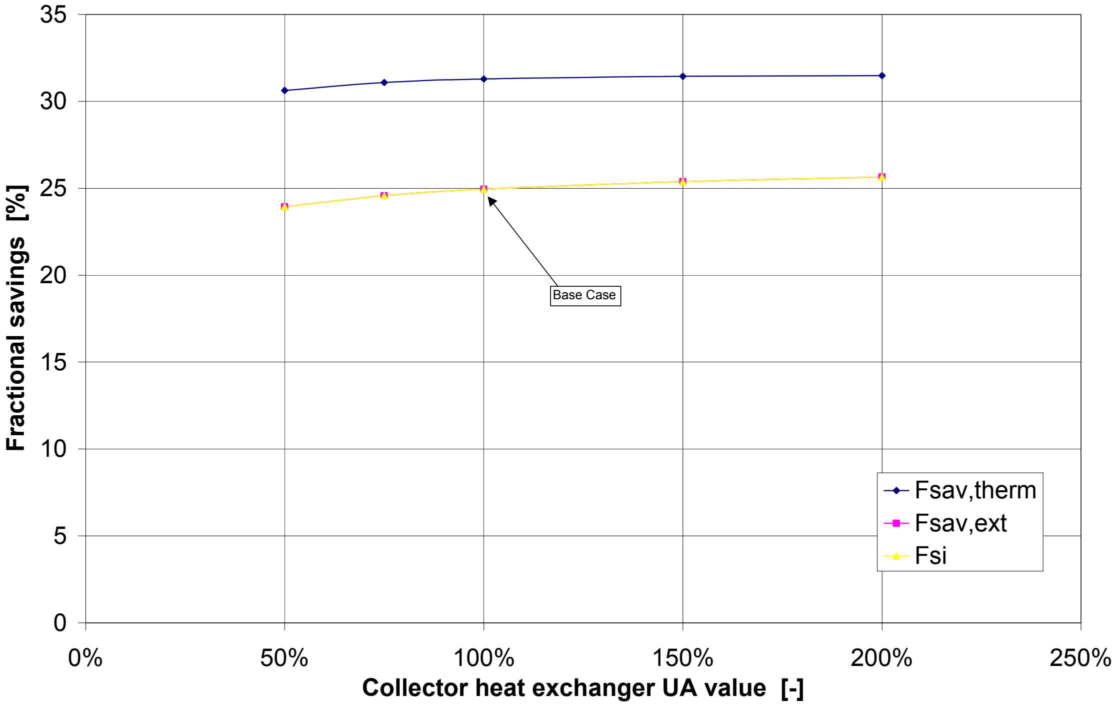


Figure 9. Variation of fractional energy savings with the UA-value of the collector heat exchanger. Parameter values are relative to the values defined for the base case system.

Differences from Base Case

None

Description of Results

Below the base case value (50 W/m² collector), the savings decrease increasingly rapidly. Above this value, there is only a marginal improvement in the savings.

Comments

None.

Sensitivity parameter:	Space heating Heat Exchanger UA (variation from base case value)	-50% - +100%

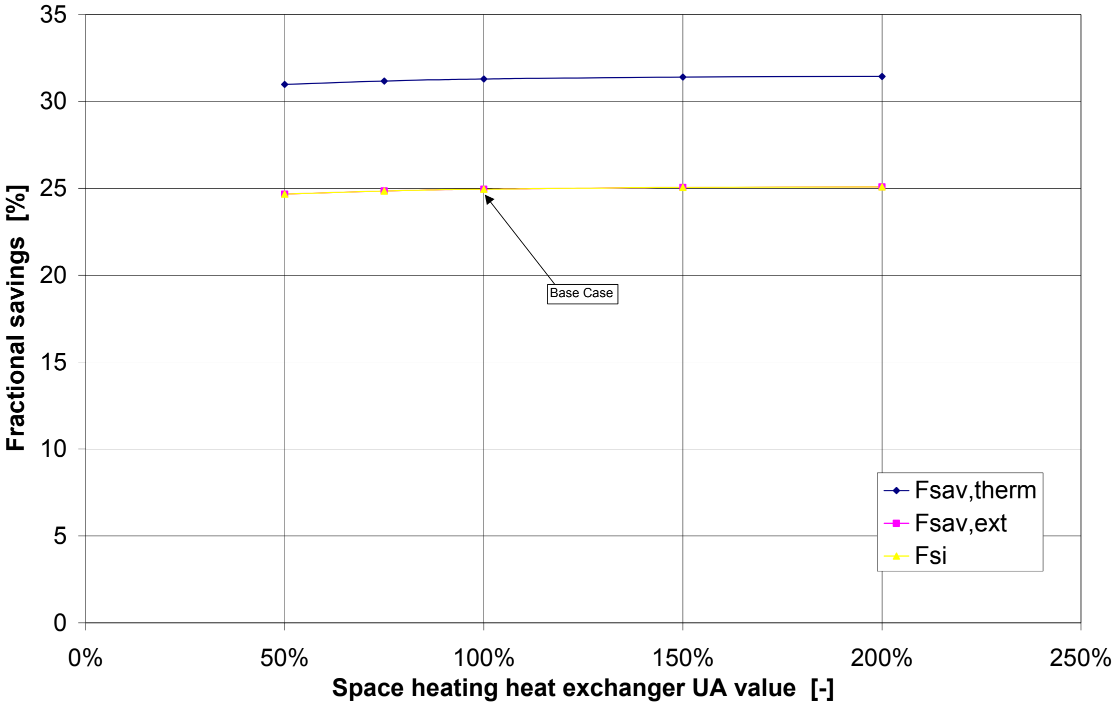


Figure 10. Variation of fractional energy savings with the UA-value of the space heating heat exchanger. Parameter values are relative to the base case UA-value.

Differences from Base Case
None

Description of Results
Within the investigated range, the UA-value has no influence on the savings.

Comments
None.

Sensitivity parameter:	Auxiliary Heat Exchanger UA (variation from base case value)	-50% - +100%

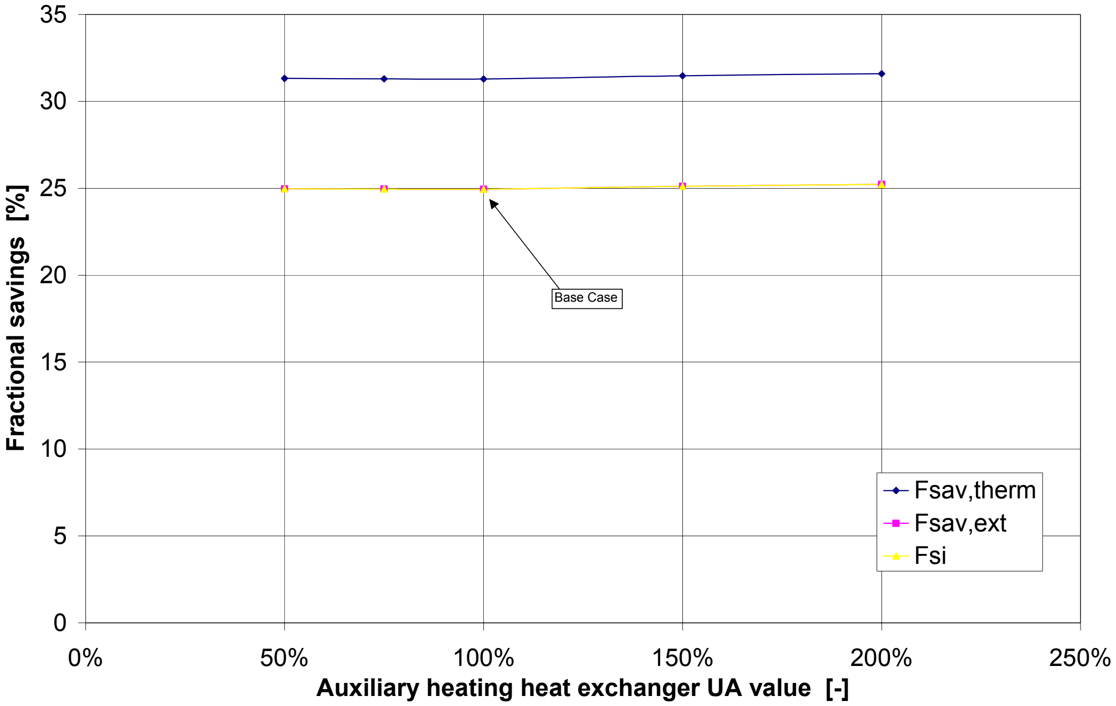


Figure 11. Variation of fractional energy savings with the UA-value of the auxiliary heat exchanger. Parameter values are relative to the base case UA-value.

Differences from Base Case
None

Description of Results
Within the investigated range, the UA-value has no influence on the savings.

Comments
None.

Sensitivity parameter:	Top insulation thickness	5 cm – 25 cm

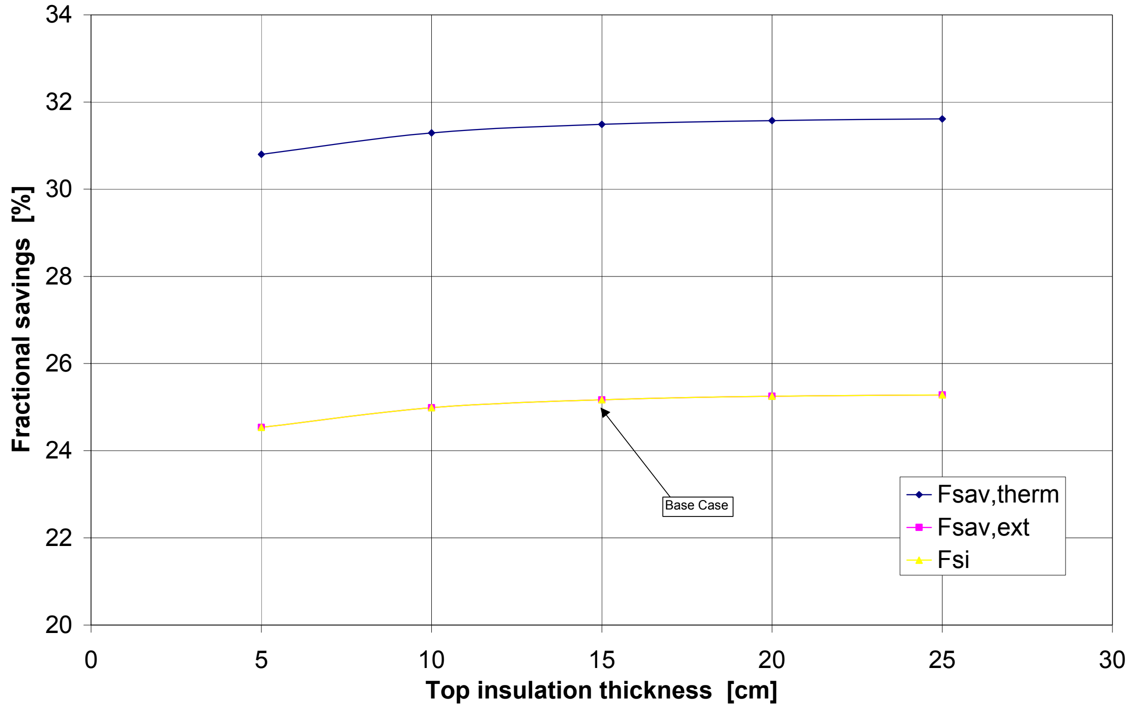


Figure 12. Variation of fractional energy savings with the top insulation thickness.

Differences from Base Case
None

Description of Results
For insulation thickness above the base case thickness of 15 cm, there is only a slight increase in savings. Below this thickness however, a decrease in the savings can be seen.

Comments
The insulation has a conductivity of 0.042 W/m-K and a correction factor for "imperfection" of C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [0.750 m^3].

Sensitivity parameter:	Side insulation thickness	5 cm – 25 cm

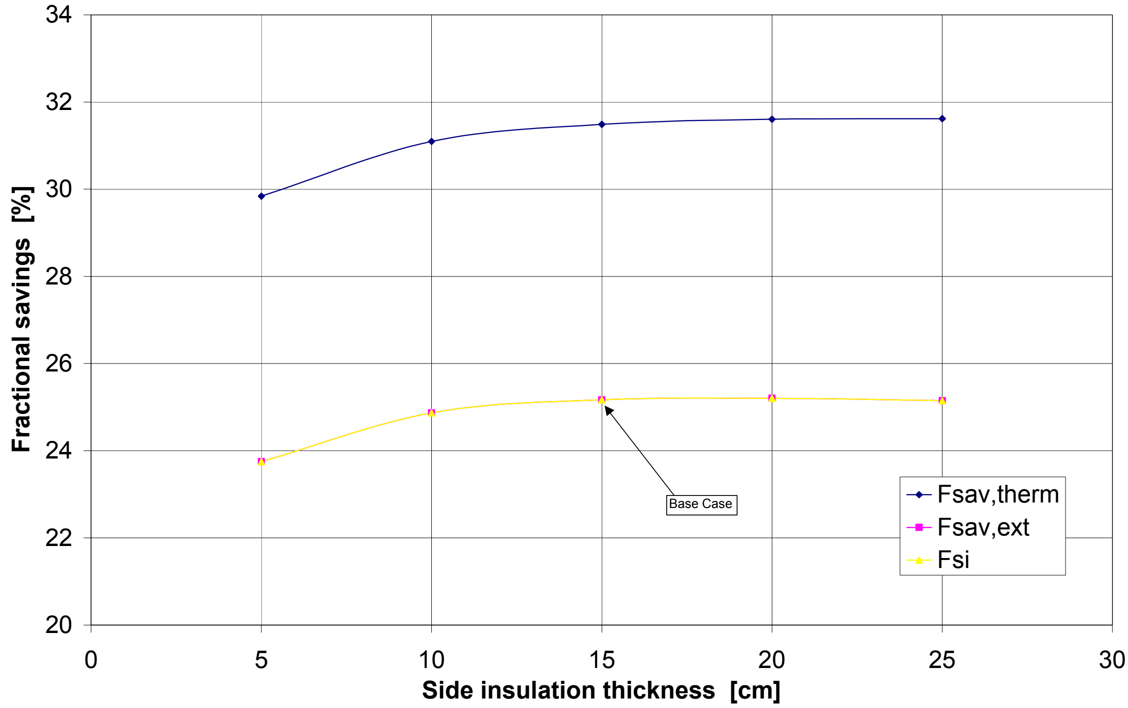


Figure 13. Variation of fractional energy savings with the side insulation thickness.

Differences from Base Case
None

Description of Results
For insulation thickness above the base case thickness of 15 cm, there is only a slight increase in savings. Below this thickness however, a decrease in the savings can be seen.

Comments
The insulation has a conductivity of 0.042 W/m-K and has a correction factor for "imperfection" of C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [0.750 m³].

Sensitivity parameter:	Bottom insulation thickness	0 cm – 25 cm

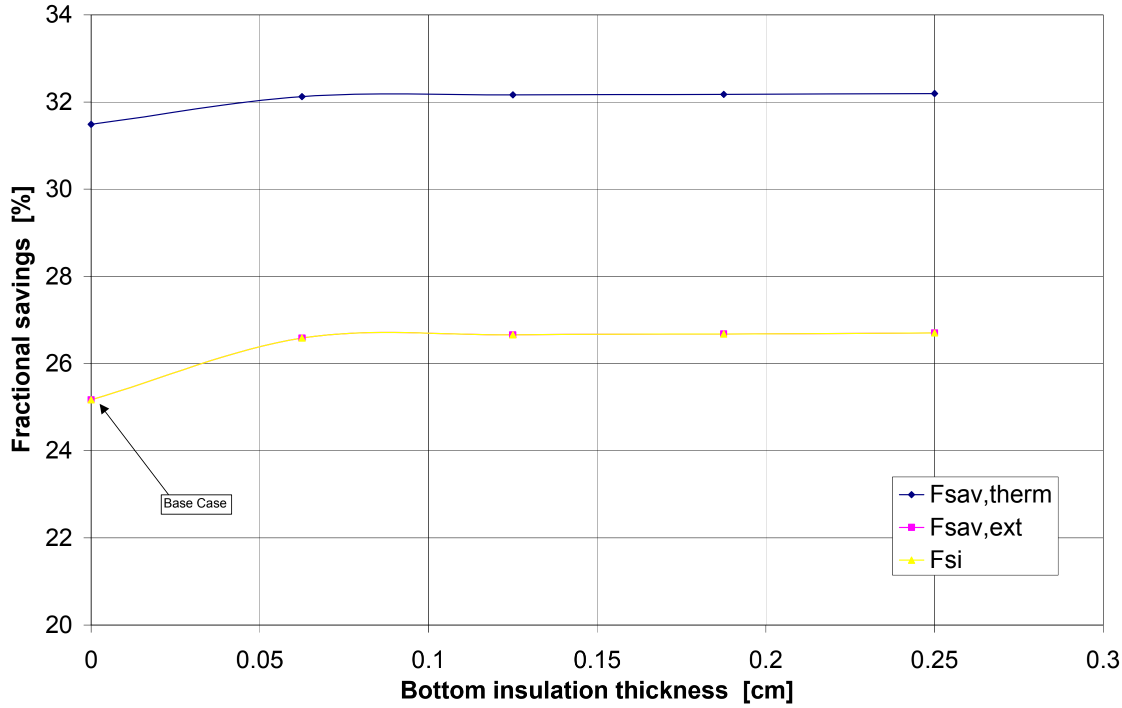


Figure 14. Variation of fractional energy savings with the bottom insulation thickness.

Differences from Base Case

None

Description of Results

For a bottom insulation thickness above approximately 5-6 cm, there is only a slight increase in savings. Below this thickness however, a decrease in the savings can be seen.

Comments

The insulation has a conductivity of 0.042 W/m-K and has a correction factor for "imperfection" of C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [0.750 m³].

Sensitivity parameter:	Store insulation thickness	5 cm – 25 cm

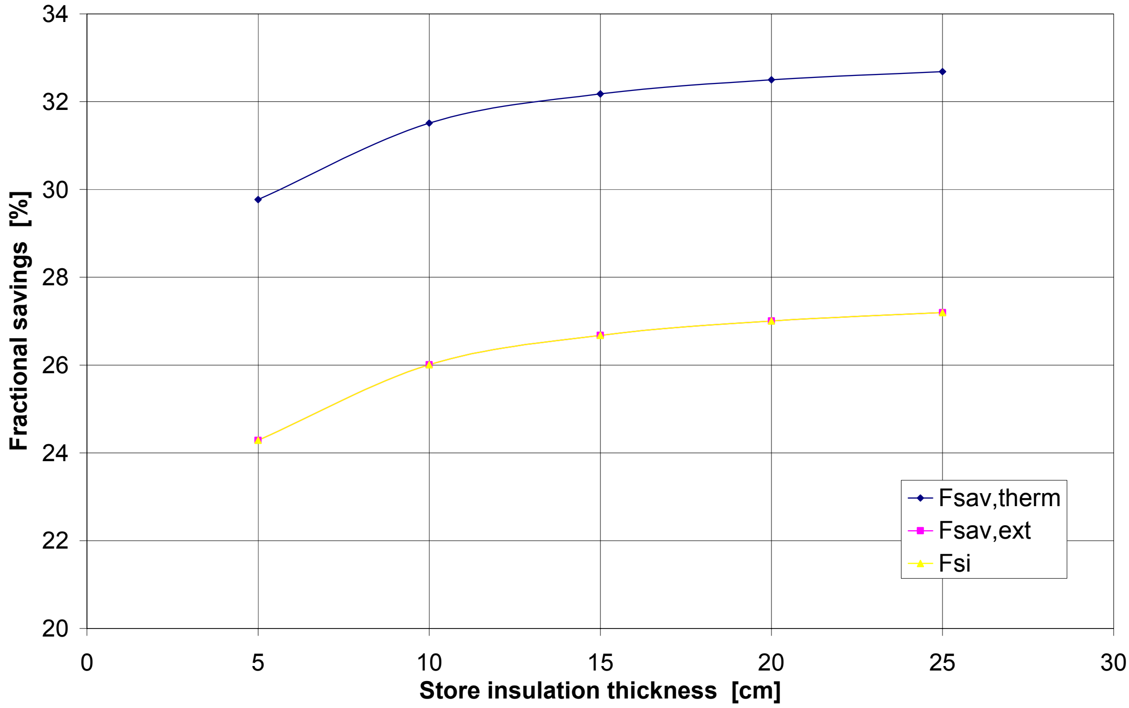


Figure 15. Variation of fractional energy savings with the store insulation thickness.

Differences from Base Case
None

Description of Results
In this case, the top-, the side- and the bottom insulation thickness are assumed equal. The figure shows that the savings increase with the thickness, however, for insulation thickness above 15 cm the increase in the savings is not so significant.

Comments
The insulation has a conductivity of 0.042 W/m-K and has a correction factor for "imperfection" of C_{corr}=Max[1.1,(1.5-V/10)] where V is the storage volume [0.750 m³].

Sensitivity parameter:	Collector Controller dT_{start} [K] (dTstop = 2 K)	2 K – 30 K

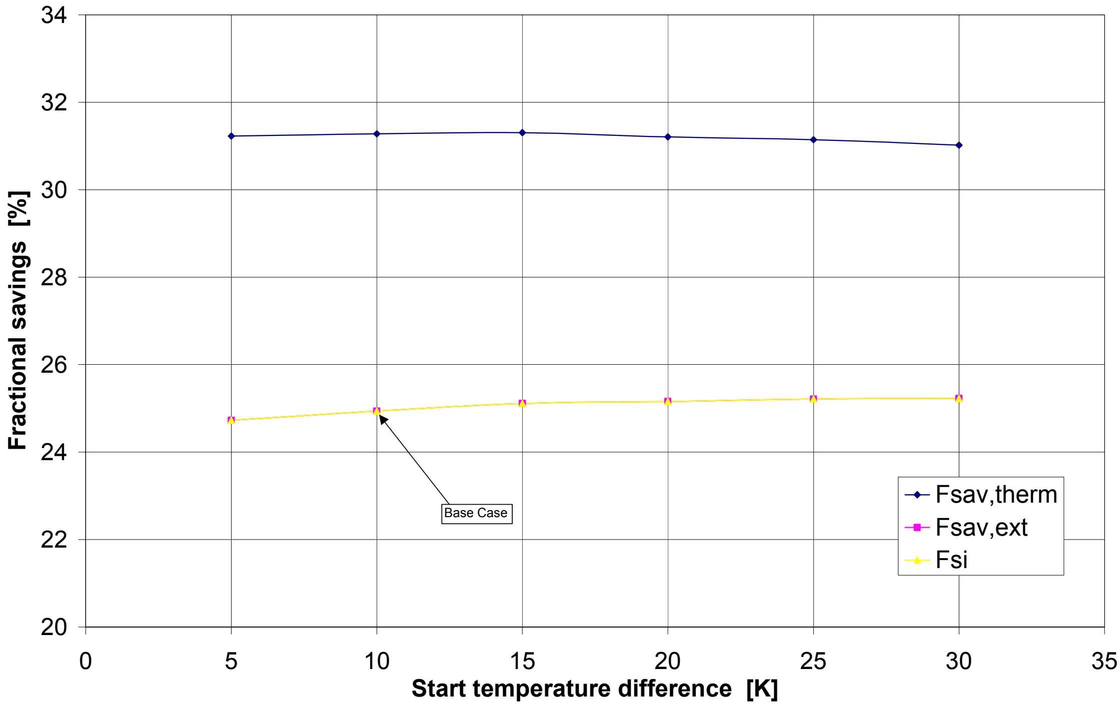


Figure 16. Variation of fractional energy savings with collector control start temperature difference.

Differences from Base Case
None

Description of Results
The thermal fractional saving has an optimum at a start temperature difference of around 15 K, however the extended fractional savings, which include the parasitic energy, has an optimum for a start difference of about 25 K. This means that the decrease in the thermal performance for start differences between 10 K and 25 K is outbalanced by the reduced electrical consumption of the collector loop pump.

Comments
None

Sensitivity parameter:	DHW set temperature [°C]	40°C – 60°C

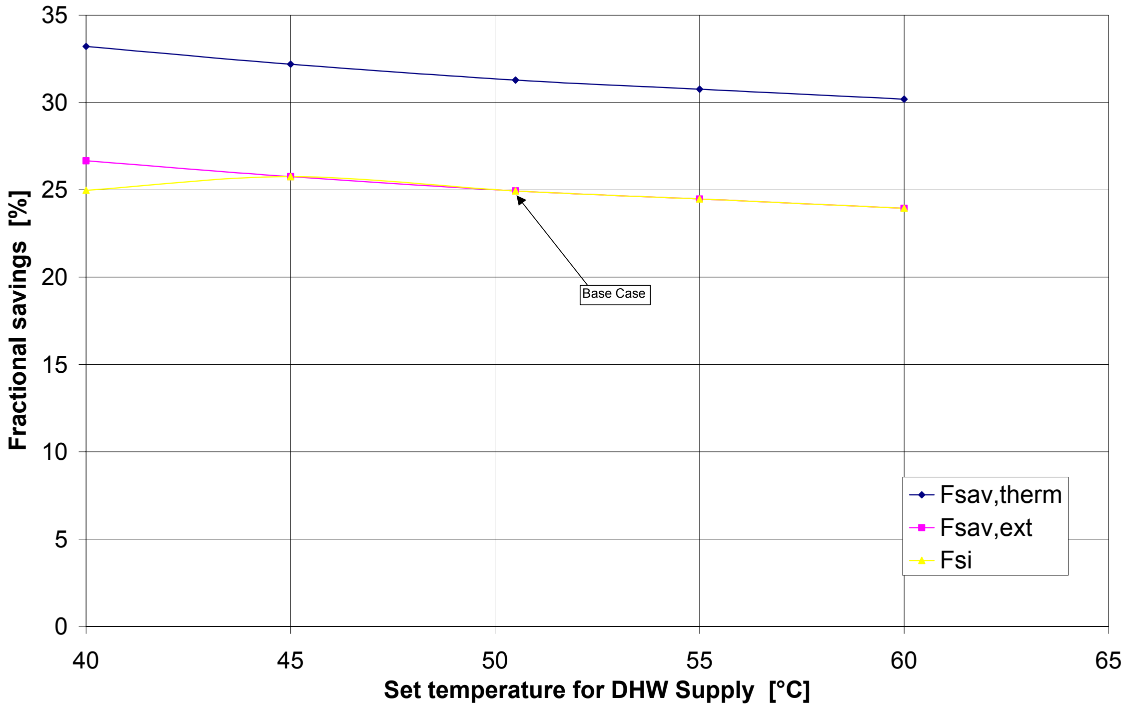


Figure 17. Variation of fractional energy savings set temperature for DHW supply.

Differences from Base Case
None

Description of Results
The fractional savings are influenced by the set temperature for the domestic hot water. The graph shows that for lower set temperatures, higher thermal and the extended fractional savings can be achieved. It can also be seen, that for set temperatures below 45°C the fractional savings indicator decreases, which means that the comfort level is not reached.

Comments
None

Sensitivity parameter:	Collector Control Sensor Rel. Height [-]	0.02 – 0.3

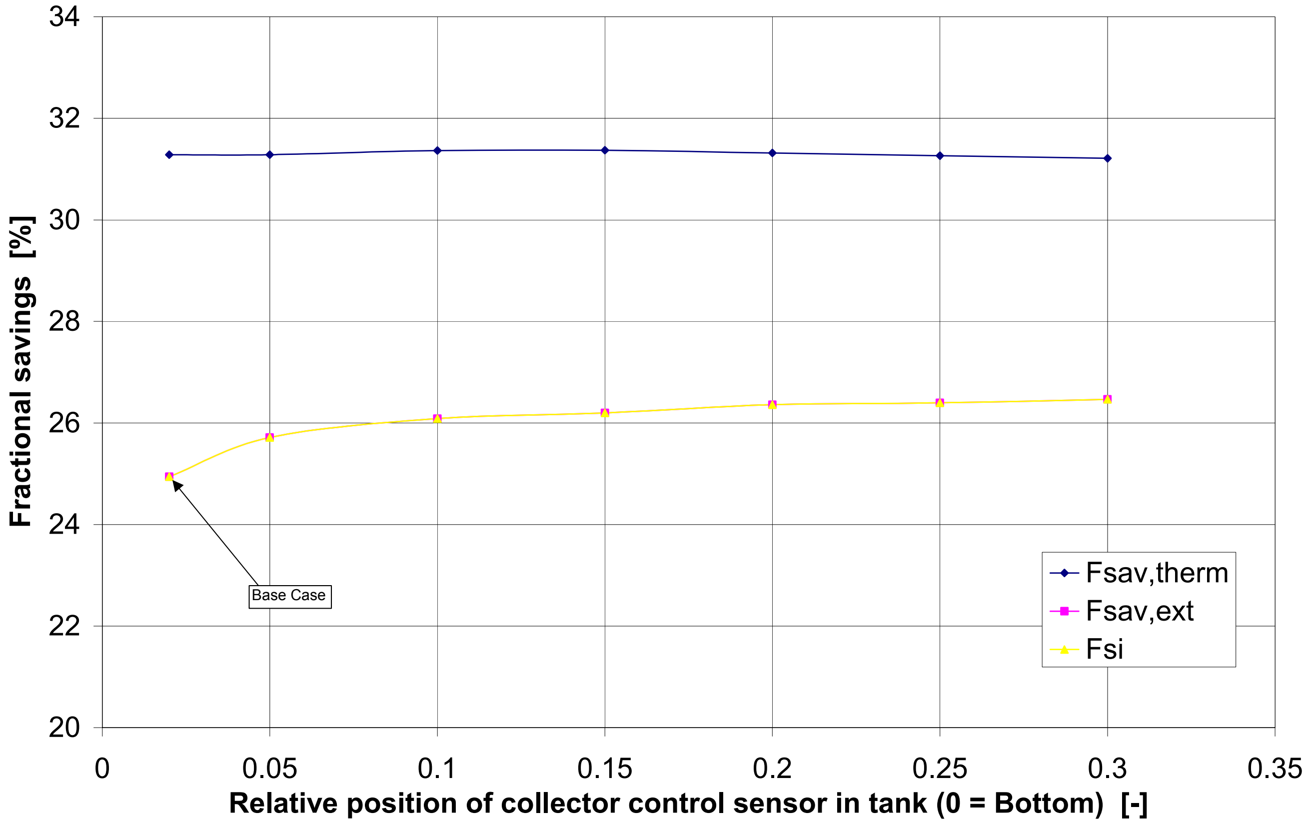


Figure 18. Variation of fractional energy savings with the position of the store sensor for the collector control.

Differences from Base Case
None

Description of Results
From the figure it appears, that the collector control sensor should be placed at least 10 % up in the tank. The solar heat exchanger is placed in the lower 1/3 of the tank and this means that the collector control sensor should be placed approximately in "the middle" of the heat exchanger.

Comments
None

Sensitivity parameter:	Space heating Controller Sensor Rel. Height [-]	0.4-0.7

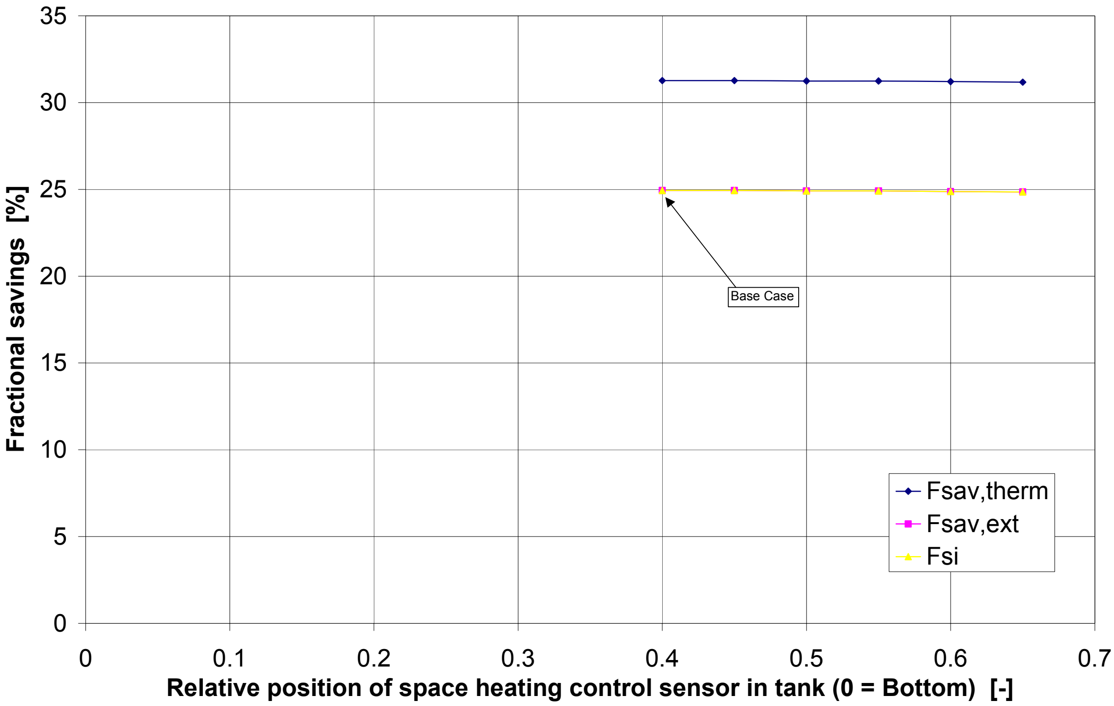


Figure 19. Variation of fractional energy savings with the position of the space heating control sensor.

Differences from Base Case
None

Description of Results
Within the investigated range, the position of the space heating control sensor has no influence on the savings.

Comments
None

Sensitivity parameter:	Climate (60 kWh SFH – Base Case)	Carpentras/Zurich/ Stockholm

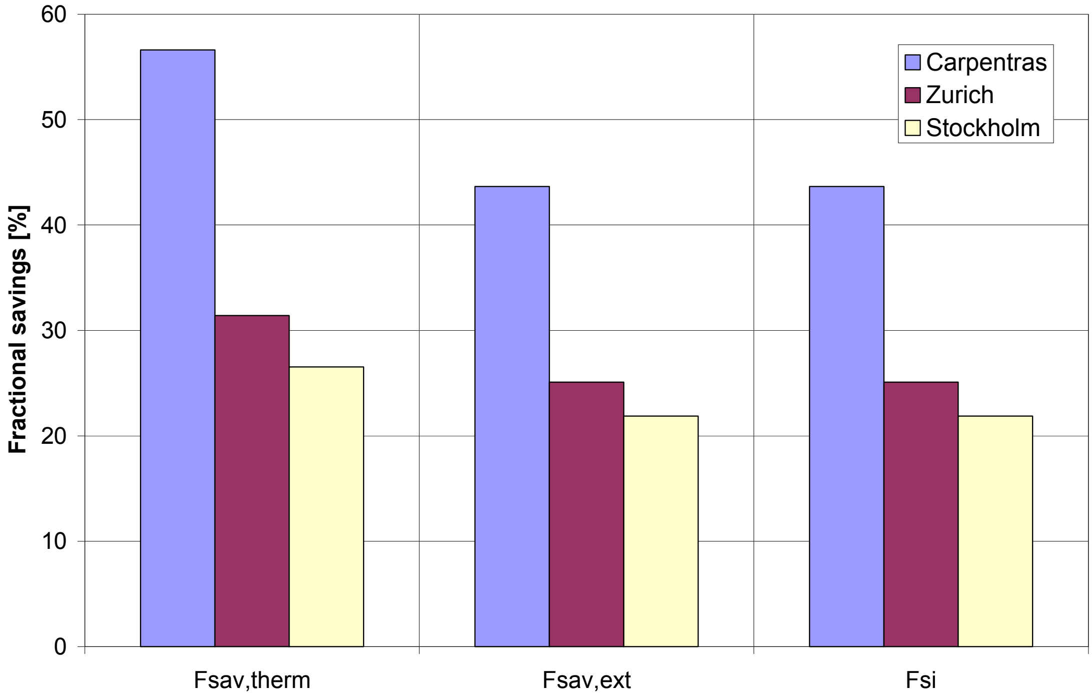


Figure 20. Variation of fractional energy savings for different climates.

Differences from Base Case
None

Description of Results
The results show that fractional savings for the Carpentras climate is much higher than for Stockholm and Zurich. Results for Stockholm and Zurich are quite similar despite the large geographic separation in latitude.

Comments
None

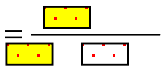
4.1.2 FSC results

In order to compare fractional savings for different climate and loads the following parameter, called **Fractional Solar Consumption (FSC)** is defined. It represents the proportion of energy consumptions for space heating and DHW which are "in phase" with available solar energy.

$$FSC = \frac{\sum_{1}^{12} \min(Cons_{ref},\ A \cdot H)}{\sum_{1}^{12} Cons_{ref}}$$

where

$Cons_{ref}$	is the monthly reference consumption without solar combisystem (kWh).
A	is the solar collector area (m²)
H	is the monthly global irradiation in the collector plane (kWh/m²)

Figure 21 illustrates the definition of FSC : $FSC =$  and in Appendix 3.1, full details about the method are given.

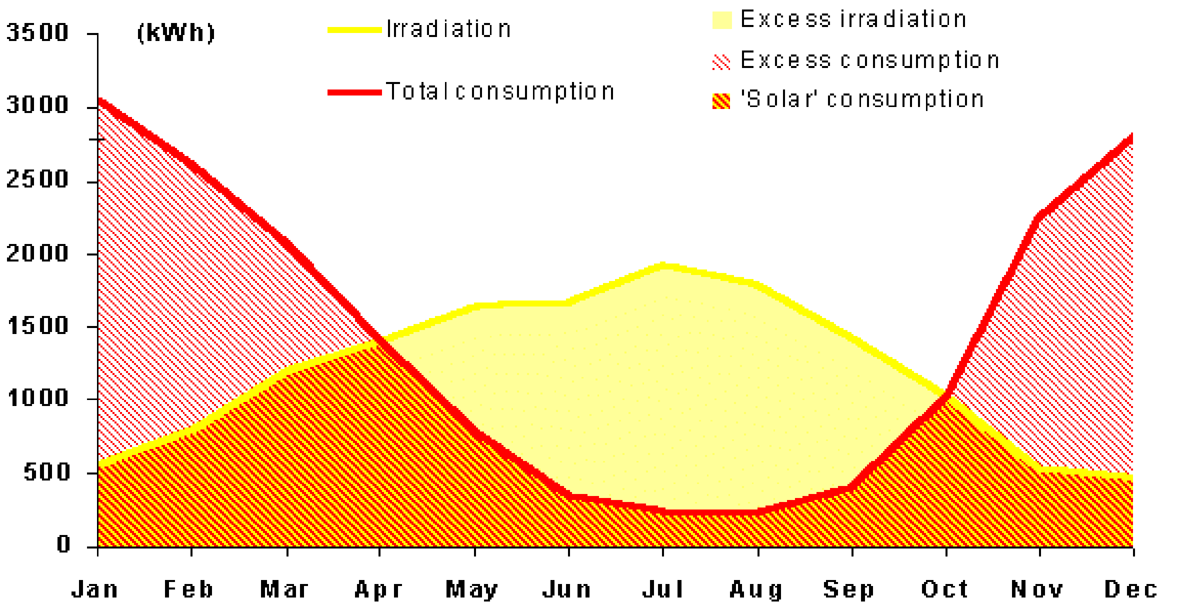


*Figure 21: D*efinition of the fractional solar consumption FSC

Figure 22 shows the fractional savings for the base case combisystem for:

- 3 climates: Stockholm, Zurich and Carpentras
- 3 collector areas: 5 m², 15 m ² and 25 m ²
- 3 space heating loads: SFH 30 kWh/m², SFH 60 kWh/m² and SFH 100 kWh/m²
- 1 domestic hot water load: 200 l/day

As an example, the figure shows that for a FSC value of 0.6 the thermal fractional saving is around 33% whereas the extended fractional saving is around 25%.

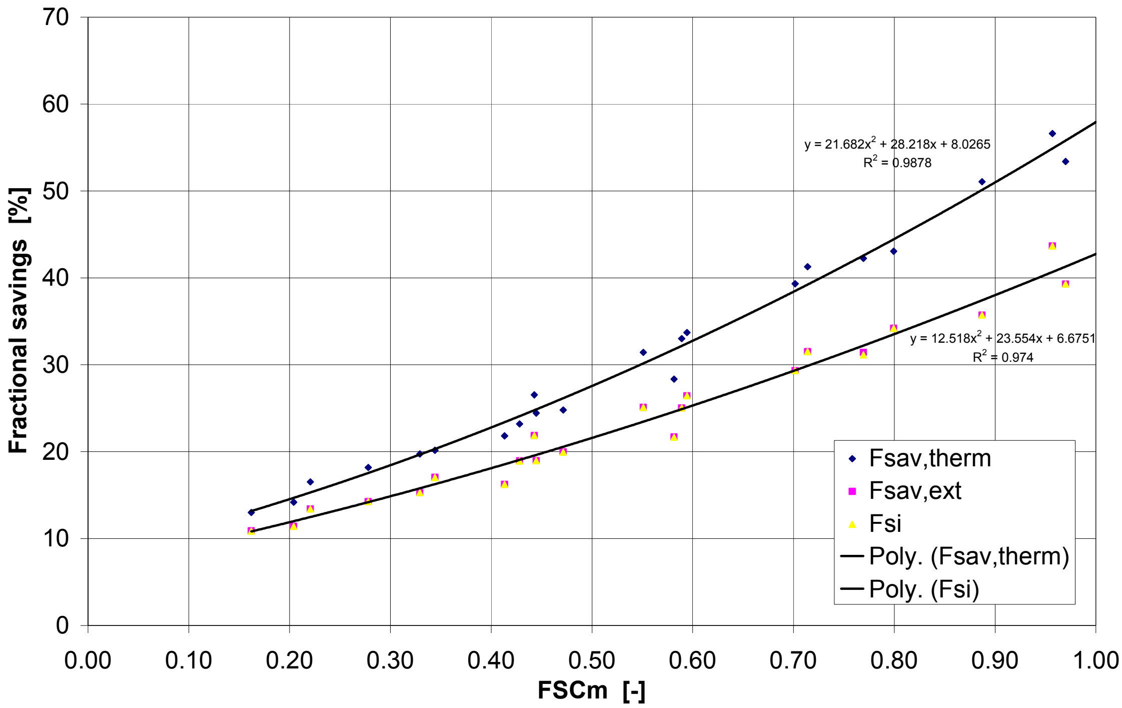


Figure 22: Fractional savings for the base case combisystem as a function of the FSC-value for 3 climates (Carpentras, Zurich, Stockholm) and 3 loads (30, 60, 100 kWh/m²a single family buildings).

4.2 Definition of the improved system

Based on the sensitivity analysis, a suggestion for an improved system is made. The major differences from the base case systems are that:

- The auxiliary volume is reduced to 0.075m³
- An electrical heating element is used in the storage tank during summertime
- The bottom of the storage is better insulated (5 cm of insulation)
- There are no thermal bridges (no correction for insulation imperfection)
- The storage temperature sensor for the collector control is moved up to the level of the collector heat exchanger inlet.
- The auxiliary set temperature is reduced to 45°C

4.2.1 FSC results for the improved system

Figure 23 shows the fractional savings for the base case combisystem for:

- 3 climates: Stockholm, Zurich and Carpentras
- 3 collector areas: 5 m², 15 m ² and 25 m ²
- 3 space heating loads: SFH 30 kWh/m², SFH 60 kWh/m² and SFH 100 kWh/m²

- 1 domestic hot water load: 200 l/day

Now, the figure shows that for a FSC value of 0.6 the thermal fractional saving is around 38% whereas the extended fractional saving is around 34%.

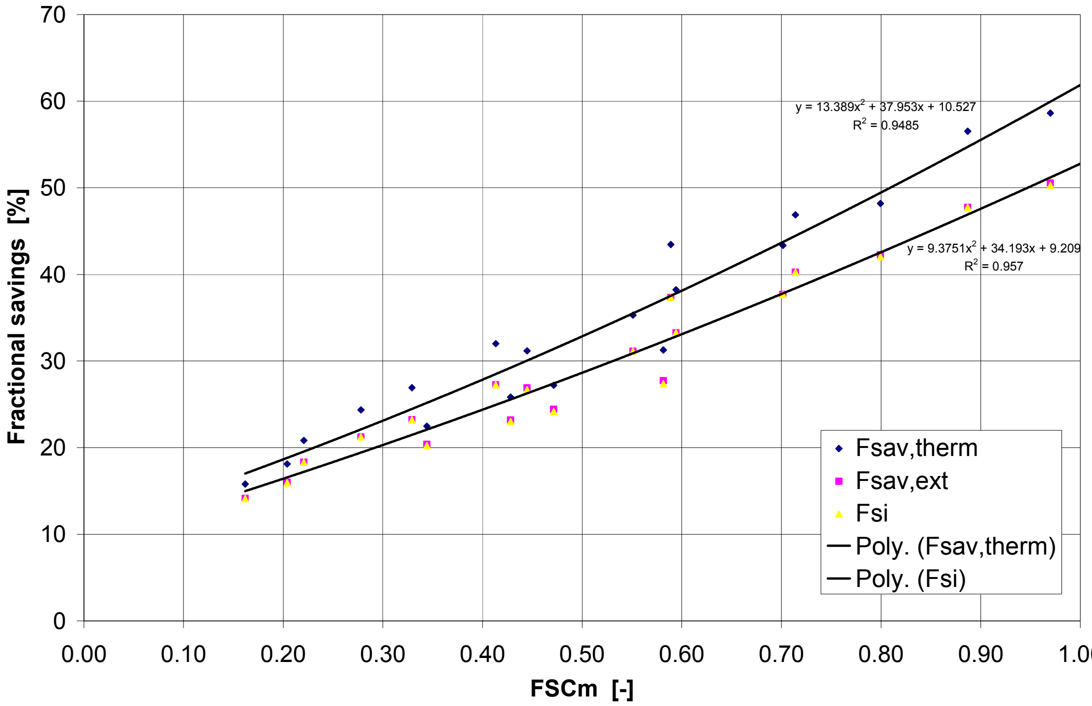


Figure 23: Fractional savings for the improved combisystem as a function of the FSC-value for 3 climates (Carpentras, Zurich, Stockholm) and 3 loads (30, 60, 100 kWh/m²a single family buildings), Improved system.

5 Conclusion

A Danish solar combisystem is theoretically investigated in this report.

The principle of the system is that it is a standard solar domestic hot water system, in which the collector area has been oversized, in order to be able to deliver energy to an existing space heating system. This is made through an extra heat exchanger included in the DHW tank.

A TRNSYS model of the system is developed and a sensitivity analysis is performed by means of TRNSYS simulation. This analysis showed that the system could be improved by:

- Reducing the auxiliary volume
- Using an electrical heating element in the storage tank during summertime
- Insulating the bottom of the storage better
- Eliminating all thermal bridges in the storage tank insulation
- Moving up the storage temperature sensor for the collector control to the level of the collector heat exchanger inlet.
- Reducing the auxiliary set temperature to 45°C

By improving the system, the thermal fractional saving can be increased about 5%pts.

6 References

[1] Klein S.A et al. (1996): TRNSYS 14.1, User Manual. University of Wisconsin Solar Energy Laboratory.

[2] Drück, H. & Pauschinger, T. (1997) Multiport Store - Model for TRNSYS Type 140 version 1.90, Institut für Thermodynamik und Wärmetechnik, Universität Stuttgart.

[3] Bales, Chris TRNSYS Type 170 Gas/Oil/Biomass.boiler module. Version 3.00. Högskolan Dalarna, Solar Energy Research Center – SERC, EKOS. S-78188 Borlänge

Appendix 1: Milestone Report C0.2

SHC -TASK 26: SOLAR COMBISYSTEMS

SUBTASK C
MILESTONE REPORT C 0.2
REFERENCE CONDITIONS
(green marks revisions at Experts meeting Rapperswil)
(yellow marks revisions at Experts meeting Oslo)

COMPILED BY W. STREICHER, R. HEIMRATH

CLIMATE, DHW- DEMAND, SH-DEMAND, REFERENCE BUILDINGS, AUXILIARY HEATER, SOLAR PLANT, ELECTRICITY CONSUMPTION

MAY 03, 2002

With inputs from:

Bales, Ch., SERC, Borlänge, Sweden
Beckman, B., SEL, Uni Wisconsin, Madison, USA
Bony, J, EIVD, Yverdon-les-Bains, Switzerland
Drueck, H., ITW, Uni Stuttgart, Germany
Frei, U., SPF-HSR, Rapperswil, Switzerland
Hadorn, J.-C., Swiss Research Program, Bournens, Switzerland
Heimrath, R., IWT TU-Graz, Austria
Jaehnig, D., SOLVIS, Braunschweig, Germany
Jordan, U., Uni Marburg, Germany
Krause, Th, SOLVIS, Braunschweig, Germany
Letz. Th. ASDER, Saint Alban-Leysse, France
Overgaard, L., L., DTI, Aarhus, Denmark
Perers, B., Vattenfall, Nyköping, Sweden
Papillon, Ph, Clipsol, Aix-les-Bains, France
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Visser, H., TNO, Delft, Netherlands
Vogelsanger, P., SPF-HSR, Rapperswil, Switzerland
Weiss, W., AEE-Intec, Gleisdorf, Austria

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1 Introduction

In order to make a comparison of the different solar combisystems of Task 26 possible, detailed reference conditions are defined in Subtask C in combination with Subtask A in respect to international standards.

2 Climate

Major inputs from:

Jordan, U., Uni Marburg, Germany
Frei, U., SPF-HSR, Rapperswil, Switzerland
Papillon, Ph, Clipsol, Trevignin, France
Bales, Ch., SERC, Borlänge, Sweden

The following climates were chosen for the optimization

- Stockholm Sweden
- Zurich Switzerland
- Carpentras France

Table 12 shows the characteristics of the locations in respect to geographical data and design temperatures. The hourly values of climate data was calculated using the Swiss climate data generator METEONORM (1999) and long term monthly averages of global irradiance and ambient temperature. **Table 13** shows an example of the data set used for the simulations.

Table 12*: Characteristics of the locations*

Location	Latitude [°]	Ambient design Temperature [°C]	Height over sea level [m]	Solar time [h]
Carpentras	44.05	-6.	105	-9.95
Stockholm	59.31	-17.	44	3.062
Zurich	47.37	-10	413	-6.457

Table 13*: Climate data example*

hour [h]	global radiation [W/m²]	diffuse radiation [W/m²]	ambient temperature [°C]	wind speed [m/s]	relative humidity [%]	dry bulb temperature [°C]
1	0	0	-1.4	2.1	74	-5.4
2	0	0	-2.1	2.1	78	-5.4
3	0	0	-2.5	2.1	81	-5.4
4	0	0	-3.0	2.1	84	-5.3
5	0	0	-3.1	2.1	84	-5.3
6	0	0	-3.6	2.1	88	-5.3
7	0	0	-4.1	2.1	91	-5.3
.	.	.	.	.	.	.
.	.	.	.	.	.	.

3 Domestic Hot Water (DHW)-demand

Major inputs from:
Bales, Ch., SERC, Borlänge, Sweden
Frei, U., SPF-HSR, Rapperswil, Switzerland
Jordan, U., Uni Marburg, Germany
Papillon, Ph, Clipsol, Trevignin, France
Vajen, K., Uni Marburg, Germany

The definition of the DHW-demand consists of the daily demand, the hot tap water load profile (mass flow) over the day on a short timescale (simulation time step), the cold water temperature and the hot tap water temperature requirement.

- Demand per home or apartment: 200 [l/d]
- Load profile over the day ref. chapter 0 (Appendix 1)
- Cold water temperature: depending on location, see **Table 14**
- Temperature shift during the year depending on location, see **Table 14**
- Hot water temperature: 45 [^{o}C] (according to prEN 12976-2:2000)

If the required hot tap water temperature is not reached, a penalty function optionally adds extra auxiliary energy (see. Milestone Report C 3.1 Optimization Procedure).

Table 14*: Temperature shift of the cold water for the different climates (adapted from prEN 12976-2:2000)*

Location	Given by	$T_{average}$ [°C]	dT_{shift} [K]	d_{offset} [d]
Carpentras	P. Papillon	13.5	4.5	19
Stockholm	C. Bales	8.5	6.4	80
Zurich	U. Frei	9.7	6.3	60

The TRNSYS-equation for the calculation of actual cold water temperature (T_{frwat}) looks:

```
Tfrwat=Tav+dTsh*sin(360*(TIME+(273.75-doff)*24)/8760)
```

dT_{sh} [°C] average amplitude for seasonal variation
d_{off} [-] shift term (which day has maximum temperature)
T_{av} [°C] yearly average cold water temperature
T_{frwat} [°C] actual cold water temperature
TIME [-] hour of the year, TRNSYS internal value

The draw off profile for DHW was prepared by Jordan and Vajen (2000) who developed a statistical algorithm distributing events like short and medium load, shower and bath over the day. The draw off profile was delivered as (ASCII) load file (see Appendix1).

4 Space heat demand

Major inputs from:

Bales, Ch., SERC, Borlänge, Sweden
Heimrath, R., IWT TU-Graz, Austria
Streicher, W., IWT TU-Graz, Austria

4.1 Requirements of building, users and the heat distribution system

Three single family houses with the same geometry but different building physics data were defined in a way that the specific yearly space heat demand for Zurich climate amounts to 30, 60 and 100 kWh/m²a. Additionally a multi family building with 5 apartments and a specific yearly space heat demand for Zurich of 45 kWh/m²a was defined. **Table 15** shows the reference data of space heat demand, the layout of the radiator heat distribution system and the name of the building file (for TRNSYS Input) of the reference buildings.

Table 15 *Reference data for one family house with 140 m² gross area (Zurich conditions)*

space heat demand *) [kWh/m² a]	**design temp. for heat distribution system** [°C]	**Δt heat distribution system** [K]	**name of *.bui-file**
100	60 (45**))	10(5**))	Refbu1oz.bui
60	40	5	Refbu6oz.bui
30	35	5	Refbu3oz.bui
45*)**	40	5	Refbumf.bui

*) ... gross area
**) ... recommended for the French solar floor system
***) ... multiply family house with flats - 100 m² gross area

Chapter 5 shows the principal design of the buildings. In chapter 5.1 the internal gains by persons and others, the ventilation rate and the building physics data are given. Chapter 6 summarizes the technical data of the heat distribution system and the design heat load for the reference buildings.

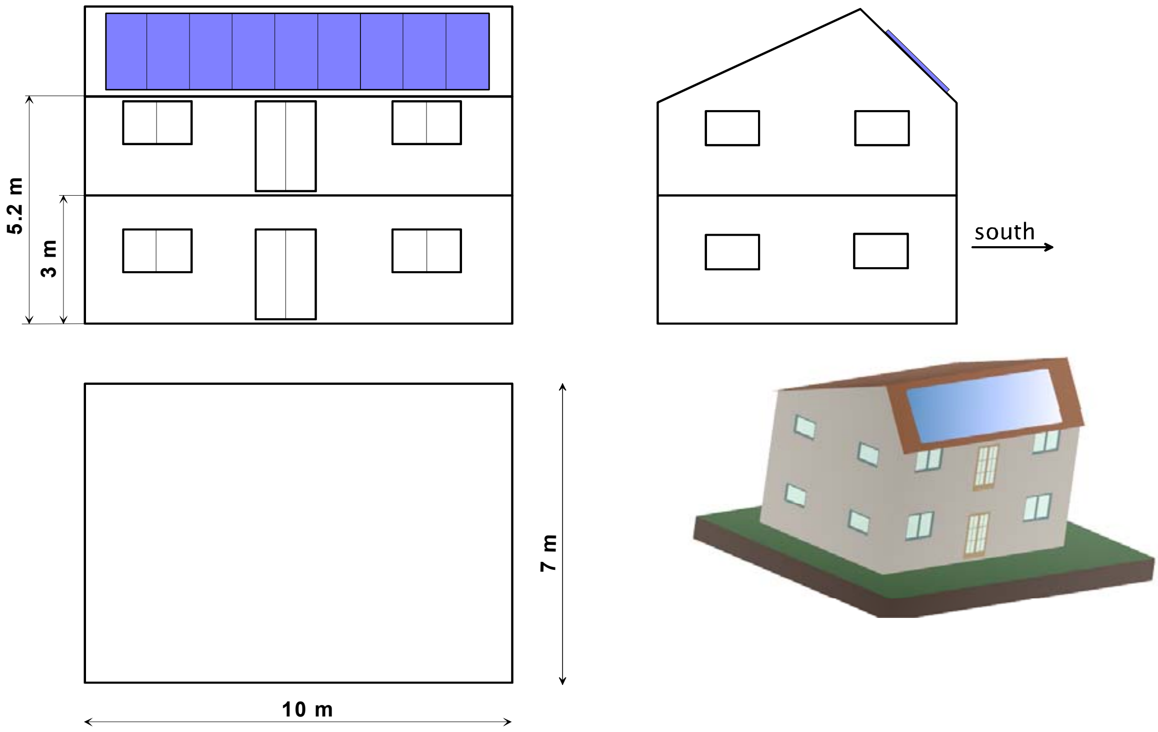
Room temperature: t_R = 19.5 – 24 °C for all systems with storage for space heating

If the required room temperature range is not reached, a penalty function optionally adds extra auxiliary energy (see. Milestone Report C 3.1 Optimization Procedure).

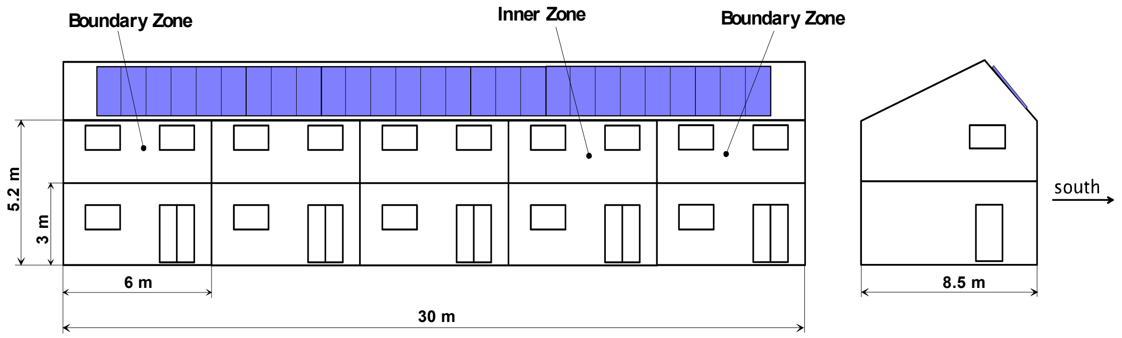
The space heating is performed with radiators (non-standard TRNSYS TYPE 162, radiator with thermal mass) and thermostatic valves adjusting the mass flow simulated with a PID controller (non-standard TRNSYS TYPE 120). Floor heating systems are calculated with non-standard TRNSYS TYPE 100 (floor heating, calculated with transfer functions).

5 Design of the reference houses

Single family house (SFH)



Multi family house (MFH)



5.1 Building physics data

45 kWh/m²a multi family house (MFH)

Windows:

Type: 2001, u-value: 1.4 W/m²K, g-value: 0.589, no internal or external shading device

Areas: m²

	East	West	North	South
Boundary Zone	[3.5]	[3.5]	2	8
Inner Zone	0	0	2	8
Sum	3.5	3.5	10	40

Gains

Boundary Zone: 2 Persons 8h seated at rest (ISO 7730) (100W) and 1 Person 9,5h seated at rest (ISO 7730) (100W)
Other gains: 550 kJ/h, constant (~150 W)

Inner Zone: 2 Persons 8h seated at rest (ISO 7730) (100W) and 1 Person 9,5h seated at rest (ISO 7730) (100W)
Other gains: 550 kJ/h, constant (~150 W)

Ventilation with the Outside
Air change of ventilation: 0.4 h^{-1}

Wall descriptions

Wall to external (from inside to outside), u-value: 0.370 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum	0.01	1.26	1	1200
Brick	0.38	1.3	1	700
Polystyrol	0.05	0.13	1.25	25
Plaster	0.02	5.04	1	2000

Roof (from inside to outside), u-value: 0.222 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum/plate	0.02	0.76	1	900
Wood-Rockwoll-comb.	0.25	0.216	1.12	144
Wood	0.02	0.47	1	600

Ground-Floor (from inside to outside), u-value: 0.231 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Wood	0.012	0.47	1	600
Flooring	0.08	5.04	1	2000
Polystyrol	0.15	0.14	1.25	30
Concrete	0.25	5.76	1.	2000

Celling between Zones (from inside to outside), u-value: 0.943 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum	0.01	1.26	1	1200

Brick	0.25	1.08	1	700
Gypsum	0.01	1.26	1	1200

Internal Wall (from inside to outside), u-value: 2.686 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Brick	0.2	3.56	1	1500

30 kWh/m²a Single family building (SFH)

Windows:

Type: 4002, u-value: 0.4 W/m²K, g-value: 0.408, no internal or external shading device

Areas: m²

	East	West	North	South
Zone One	4	4	3	12

Gains

Zone One: 2 Persons 8h seated at rest (ISO 7730) (100W) and 1 Person 9,5h seated eating (ISO 7730) (100W)
Other gains: 700 kJ/h, constant (~195 W)

Ventilation with the Outside
Air change of ventilation: 0.4 h^{-1}

Wall descriptions

Wall to external (from inside to outside), u-value: 0.135 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum/plate	0.013	0.76	1	900
Wood	0.015	0.54	1	100
Rockwoll	0.280	0.144	0.8	80
Gypsum/plate	0.013	0.76	1	900
Plaster	0.020	5.04	1	2000

Roof (from inside to outside), u-value: 0.107 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum/plate	0.026	0.76	1	900
Wood	0.015	0.54	1.	800
Rockwoll	0.320	0.13	0.9	40
Wood	0.015	0.54	1.	800

Ground-Floor (from inside to outside), u-value: 0.118 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]

Wood	0.015	0.47	1	600
Flooring	0.060	5.04	1	2000
Polyurathan	0.090	0.09	2.09	40
Polystyrol	0.160	0.13	1.25	25
Concrete	0.160	5.76	1.	2000

Internal Wall (from inside to outside), u-value: 2.686 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Brick	0.200	3.56	1	1500

60 kWh/m²a Single family building (SFH)

Windows:

Type: 2001, u-value: 1.4 W/m²K, g-value: 0.589, no internal or external shading device

Areas: m²

	East	West	North	South
Zone One	4	4	3	12

Gains

Zone One: 2 Persons 8h seated at rest (ISO 7730) (100W) and 1 Person 9,5h seated eating (ISO 7730) (100W)
Other gains: 700 kJ/h, constant (~195 W)

Ventilation with the Outside
Air change of ventilation: 0.4 h^{-1}

Wall descriptions

Wall to external (from inside to outside), u-value: 0.342 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum	0.01	1.26	1	1200
Brick	0.38	1.3	1	700
Polystyrol	0.06	0.13	1.25	25
Plaster	0.02	5.04	1	2000

Roof (from inside to outside), u-value: 0.227 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum/plate	0.02	0.76	1	900
Wood-Rockwoll-comb.	0.24	0.216	1.12	144

Wood	0.02	0.54	1.	800

Ground-Floor (from inside to outside), u-value: 0.196 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Wood	0.012	0.47	1	600
Flooring	0.06	5.04	1	2000
Polystyrol	0.18	0.14	1.25	30
Concrete	0.25	5.76	1.	2000

Internal Wall (from inside to outside), u-value: 2.686 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Brick	0.2	3.56	1	1500

100 kWh/m²a Single family building (SFH)

Windows:

Type: 1002, u-value: 2.8 W/m²K, g-value: 0.755, no internal or external shading device

Areas: m²

	East	West	North	South
Zone One	4	4	3	12

Gains

Zone One: 2 Persons 8h seated at rest (ISO 7730) and 1 Person 9,5h seated at rest (ISO 7730)
Other gains: 700 kJ/h, constant

Ventilation with the Outside
Air change of ventilation: 0.4 h^{-1}

Wall descriptions

Wall to external (from inside to outside), u-value: 0.508 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Gypsum	0.02	1.26	1	1200
Brick	0.38	1.3	1	700
Cork	0.03	0.16	1.8	100
Plaster	0.02	5.04	1	2000

Roof (from inside to outside), u-value: 0.494 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]

Concrete	0.20	5.04	1	2000
Wood-Rockwoll-comb.	0.1	0.216	1.12	144
Wood	0.01	0.47	1.	600

Ground-Floor (from inside to outside), u-value: 0.546 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Wood	0.01	0.47	1	600
Flooring	0.06	5.04	1	2000
Polystyrol	0.05	0.13	1.25	25
Concrete	0.25	5.76	1.	2000

Internal Wall (from inside to outside), u-value: 2.686 W/m²K

Type	Thickness [m]	Therm cond. [kJ/hmK]	Therm. cap. [kJ/kgK]	Density [kg/m³]
Brick	0.2	3.56	1	1500

6 Space heat demand and heat distribution system

The space heat distribution system is defined as an ambient temperature controlled radiator system with thermostatic valves adjusting the mass flow according to variable inner heat loads. Table 16 lists the specifications of this system for the different buildings and climates.

The heat loads according to DIN 4701 for the four building types in the various climates were calculated with the design temperature for each climate with TRNSYS (without gains and solar radiation).

The standard specific heating capacity of the radiators ($\dot{Q}_N = 1263\ W/m$) was derived from Recknagel, Sprenger, 1992 for a two rows radiator with 0.6 m height. The actual specific heating capacity was recalculated by $\dot{Q} = \dot{Q}_N \cdot \left(\Delta T / \Delta T_N\right)^{radiater\,\exp}$.

***Table 16**: Specifications of the heat distribution system – constant flow rate and radiator area*

Zürich clima file

standard	heat load DIN 4701 Q_{4701} [W]	heatcap. radiator q_N [W/m]	height radiator $h_{rad.}$ [m]	area radiator A_{R_N} [m²]	incoming temperature t_{in} [°C]	temperature difference Δt_{rad} [°C]	temp.-diff room-radia. Δt_N [°C]
Refbu30	2830	1263	0,6	1,34	35	5	60
Refbu60	4950	1263	0,6	2,35	40	5	60
Refbu100	7290	1263	0,6	3,46	60	10	60
RefbuMF	13970	1263	0,6	6,64	40	5	60

real	temp.-diff room-radia. Δt [°C]	radiator-exponent n [-]	heatcap. radiator q_{real} [W/m]	area radiator A_{R_real} [m²]	flow rate constant m [kg/s]	flow rate constant m [kg/h]	length radiator A_{R_real} [m]
Refbu30	12,5	1,3	164,36	10,33	0,135	487,5	17,22
Refbu60	17,5	1,3	254,54	11,67	0,237	852,6	19,45
Refbu100	35	1,3	626,75	6,98	0,174	627,8	11,63
RefbuMF	17,5	1,3	254,54	32,93	0,668	2406,3	54,88

Carpentras clima file

standard	heat load DIN 4701 Q_{4701} [W]	heatcap. radiator q_N [W/m]	height radiator $h_{rad.}$ [m]	area radiator A_{R_N} [m²]	incoming temperature t_{in} [°C]	temperature difference Δt_{rad} [°C]	temp.-diff room-radia. Δt_N [°C]
Refbu30	2460	1263	0,6	1,17	35	5	60
Refbu60	4260	1263	0,6	2,02	40	5	60
Refbu100	6320	1263	0,6	3,00	60	10	60
RefbuMF	12060	1263	0,6	5,73	40	5	60

real	temp.-diff room-radia. Δt [°C]	radiator-exponent n [-]	heatcap. radiator q_{real} [W/m]	area radiator A_{R_real} [m²]	flow rate constant m [kg/s]	flow rate constant m [kg/h]	length radiator A_{R_real} [m]
Refbu30	12,5	1,3	164,36	8,98	0,118	423,7	14,97
Refbu60	17,5	1,3	254,54	10,04	0,204	733,8	16,74
Refbu100	35	1,3	626,75	6,05	0,151	544,3	10,08
RefbuMF	17,5	1,3	254,54	28,43	0,577	2077,3	47,38

Stockholm clima file

standard	heat load DIN 4701 Q_{4701} [W]	heatcap. radiator q_N [W/m]	height radiator $h_{rad.}$ [m]	area radiator A_{R_N} [m²]	incoming temperature t_{in} [°C]	temperature difference Δt_{rad} [°C]	temp.-diff room-radia. Δt_N [°C]
Refbu30	3480	1263	0,6	1,65	35	5	60
Refbu60	6160	1263	0,6	2,93	40	5	60
Refbu100	9050	1263	0,6	4,30	60	10	60
RefbuMF	17350	1263	0,6	8,24	40	5	60

real	temp.-diff room-radia. Δt [°C]	radiator-exponent n [-]	heatcap. radiator q_{real} [W/m]	area radiator A_{R_real} [m²]	flow rate constant m [kg/s]	flow rate constant m [kg/h]	length radiator A_{R_real} [m]
Refbu30	12,5	1,3	164,36	12,70	0,167	599,4	21,17
Refbu60	17,5	1,3	254,54	14,52	0,295	1061,1	24,20
Refbu100	35	1,3	626,75	8,66	0,217	779,4	14,44
RefbuMF	17,5	1,3	254,54	40,90	0,830	2988,5	68,16

7 Auxiliary heating device

Major inputs from:

Bales, Ch., SERC, Borlänge, Sweden
Heimrath, R., IWT TU-Graz, Austria
Shah, L., J., DTU, Lyngby, Denmark
Streicher, W., IWT TU-Graz, Austria

Two reference auxiliary heating devices can be used for the simulations.
- gas burner (preferred)
- biomass

Nominal burner power: $P_{nom,burner}$: 15 kW (SFH)
$P_{nom,burner}$: 24 kW (MFH)

Table 17 Reference data of the burners

	Gas burner	**Biomass burner (automatically)**
Load range	25 – 100 %	30 – 100 %
Minimum running time	1 Minute	30 Minutes
Minimum standstill time	1 Minute	30 Minutes

The non-standard TRNSYS TYPE 170 (as modified in November 2000 by Bales) was chosen as burner model using non-standard TRNSYS TYPE 123 as controller.

burner efficiency: **Output 20 of Type 170 is used**
annual efficiency of gas-condensing burner: $\eta_{burner,gas}$ = 85 %
annual efficiency of pellets burner $\eta_{burner,bio}$ = 80 %

Q_{burner} is defined as the output 13 of the Type 170 (Q_{zuges}).

The two burners (gas and wood) will be included in the TRNSED program by radio buttons.

8 Solar plant and hydraulics

Major inputs from:

Bales, Ch., SERC, Borlänge, Sweden
Drueck, H., ITW, Uni Stuttgart, Germany
Perers, B., Vattenfall, Nyköping, Sweden
Streicher, W., IWT TU-Graz, Austria
Vajen, K., Uni Marburg, Germany

8.1 Collector

Two types of collector, a typical flat plate collector with selective surface and a typical evacuated tube, are chosen for the investigation. **Table 18** shows characteristically data for these collectors. Other collector can be chosen additionally. The non-standard TRNSYS TYPE132 (Bengt Perers model) is used for collector simulation.

Table 18 *Reference data of the 2 types of collectors (data for aperture area)*

Type	Description	$\eta 0$ [-]	a1 [W/m²K]	a2 [W/m²K²]	inc. Angle modifier (50°) [-]
1	Flat - plate selective	0.8	3.5	0.015	0.9
2	Evacuated tubular	0.77	1.85	0.0042	0.9 / 1.0
3	Actual used / recommended	differs	Differs	differs	differs

Mass flow:
1. Fixed to low or high flow (between 8 and 50 l/m²h)
2. Matched flow with simple approach may be used in a second stage

8.2 Pipes

The technical data of the pipes between collector and heat exchangers are chosen similar but not identical to prEN 12976-2:2000 as follows

Length:	30 m (total, Single Family House)	
Insulation:	< 12 mm diameter :	200% of ∅
	> 12 mm diameter :	100% of ∅
Surrounding temperature:	15 °C	

8.3 Storage (boundaries and fixed values)

Volume: open

Volume / diameter:

Vajen (Uni Marburg) made an approach for several data for store volumes between 0.6 - 2.5 m³:
H_{Store}=Max(Min(2.2,1.78+0.39*ln(V_{store})),0.8)
H_{Store} [m] height of the store
V_{store} [m³] Volume of the store
This equation is not mandatory, if actual data is available this should be used

Thermal loss

Insulation: 0 - 15 cm, λ = 0.04 W/mK
Top / bottom insulation : sensitivity analysis
Thermal loss: $\dot{Q}_{loss\_theorie} \cdot C_{corr}$
C_{corr} → Approach:
C_{corr}=MAX(1.1,(1.5-V_{store}/10))
This equation is not mandatory, if actual data is available this should be used

Number of layers for variation (open to participants)

Vertical thermal conductivity: open
if nothing is known: approach:
$\lambda_{vertikal}$=MAX(0.7,(1.3-V_{store}/10)) [W/mK]
This equation is not mandatory, if actual data is available this should be used

Surrounding temperature: 15°C

9 Electrical Final Energy

Major inputs from:

Heimrath, R., IWT TU-Graz, Austria
Jaehnig, D., SOLVIS, Braunschweig, Germany
Jordan, U., Uni Marburg, Germany
Papillon, Ph, Clipsol, Trevignin, France
Streicher, W., IWT TU-Graz, Austria

Solar systems do not only save final energy but need electricity for pumps, controllers etc. This electricity demand is optionally taken into account in the target functions for optimization (see Milestone Report C 3.1 Optimization Procedure)

W is the sum of energy needed by all the electric components included in the system. (W_{solar} for solar system, W_{ref} for reference system, see Milestone Report C 3.1 Optimization Procedure)

$$W_{solar/ref} = W_{pumps} + W_{burner} + W_{electrical\ heater} + W_{valves} + W_{controller} \qquad (kWh/a)$$

Nomenclature:

P: power (thermal and electrical)
Q: thermal energy
t: time
T: temperature
W: electrical energy
η: efficiency

Indices:

DHW : domestic hot water
el : electrical devices
int/ext : solar system with internal/external heat exchanger to store
nom: nominal
on/off : device on (running) or off (standby)
ref : conventional reference system
SH : space heating
solar : solar combisystem system
stby: standby

9.1 Pumps (Collector and others)

$$W_{pumps} = \left(t_{Solar} \cdot P_{el,pump,\mathrm{int/ext}} + t_{SH} \cdot P_{el,pump,SH} + t_{DHW} \cdot P_{el,pump,DHW} + \sum_i t_{pump,i} \cdot P_{el,pump,others,i} \right) / 1000 \quad (kWh/a)$$

$P_{el\ int/ext}$ – Solar

Pump power collector (proposal from Austria, calculated for 16 different plants (Fig. 1))

$P_{el,pump\text{-}int}$: Collector pump power for collector loops with internal heat exchanger

$P_{el,pump,ext}$: Collector pump power for collector loops with external heat exchanger (primary + secondary pump)

P_{el} – SH

Electricity demand of the pump of the heating system and running time of the pump of the heating system (time when the heating system is running):
The el. power demand of the pump of the space heating system is defined as follows (evaluated from Gertec 1999):

$P_{el,pump,SH}$ = 0.203 x $P_{nom,burner}$ +90.476 (see Fig. 3)
$P_{el,pump,SH}$ = 93 W (15 kW) and 95 W (24 kW)
t_{SH} time heating season

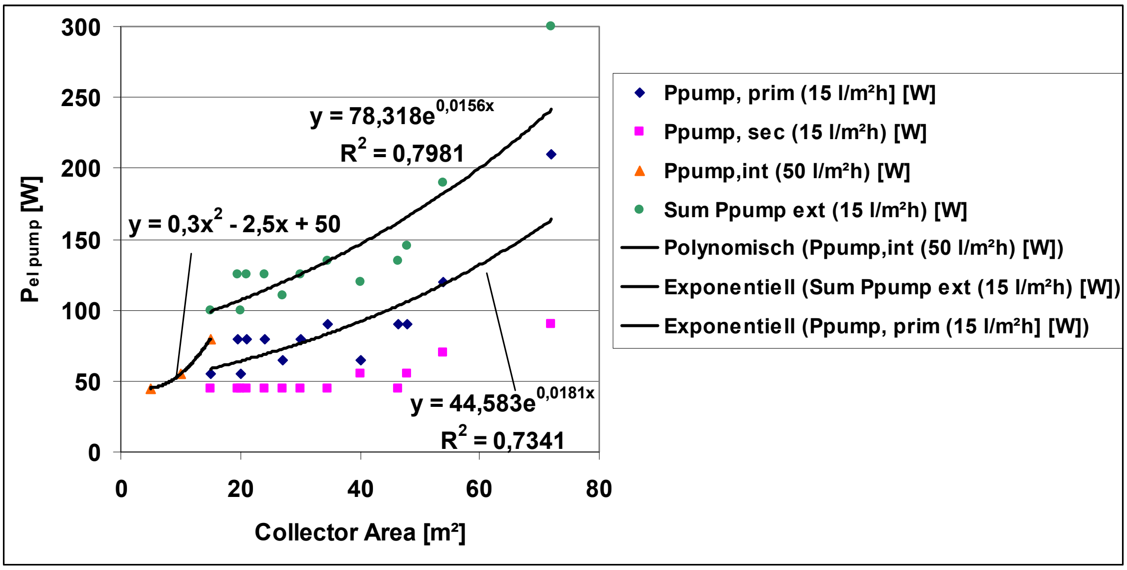


Fig. 1: Specific electrical power consumption collector loops (average curves of 3 values internal, 13 values external heat exchanger)

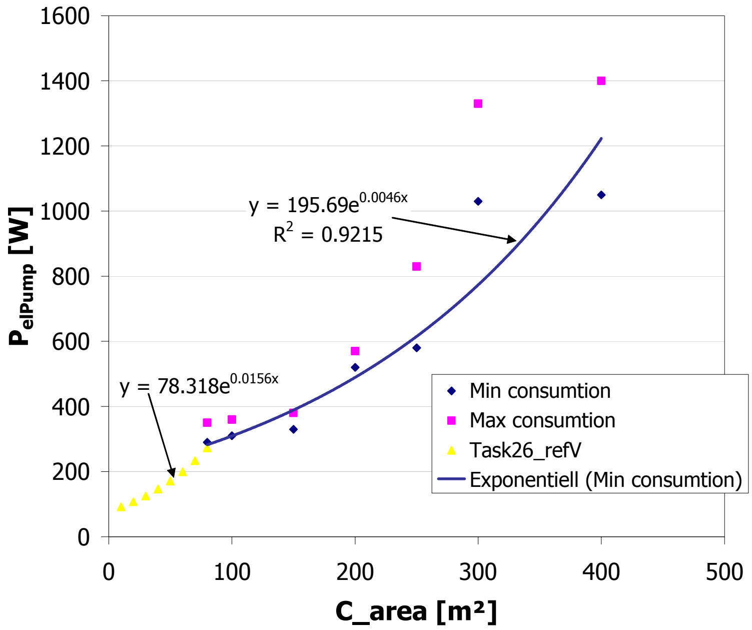


Fig. 2: Specific electrical power consumption collector loops for large collector areas (7 values external heat exchanger - Project "Solarunterstützte Wärmeversorgungskonzepte für Mehrfamilienhäuser im Vergleich")

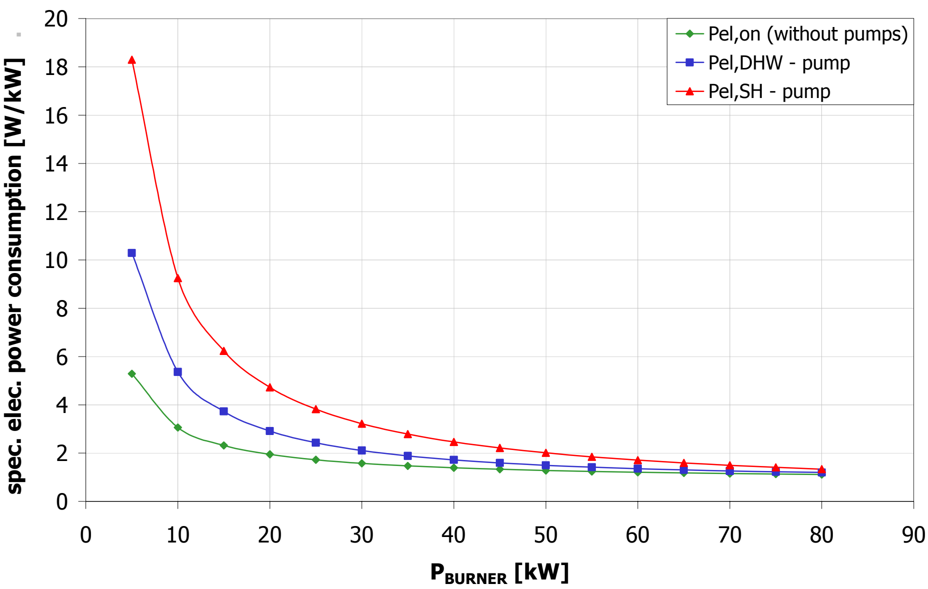


Fig. 3: Specific electrical power consumption of cond. gas burners and the DHW and SH – pumps (average curves of about 80 values each, Gertec, 1999)

P_{el} - DHW

Electricity demand of the pump for the DHW-store (i.e. 150 l) and running time of this pump

$P_{el,pump,DHW} = 49{,}355e^{(0{,}0083 \times Pnom,burner)}$

$P_{el,pump,DHW}$ = 55 W (15 kW) and 60 W (24 kW)

t_{DHW} running time DHW-loading (calculated for each system, ref: see reference system, Milestone Report C 3.1 Optimization Procedure)

Others:

Every other pump of the system has 50 W, no heat input due to the pump

9.2 Burner electricity demand

The electrical energy demand of the burner (running and standby):

$$W_{burner} = \left(P_{el,burner,on} \times t_{burner,on} + P_{el,burner,standby} \times t_{burner,standby}\right)/1000 \qquad (kWh/a)$$

with

$P_{el,burner,stby}$ = 9 W

$P_{el,burner,on}$ = 0,8349 x $P_{nom,burner}$ + 22,257 (approximation from statistics)

$P_{el,burner,on}$ = 35 W (15 kW) and 42 W (24 kW) (without heating circulation pump and DHW-loading pump);

$P_{el,off}$ = 0 when clearly stated, when it is switched off

$t_{burner;on}$ and $t_{burner,standby}$ are defined by the output 13 of TRNSYS TYPE (Q_{zuges}).

9.3 General electricity demand

- $W_{electrical\ heater}$ =nominal power · running time *(kWh/a)*
- W_{valves} is neglected
- $$W_{controller} = \frac{(number\ of\ electric\ outputs\ of\ the\ controller) \cdot 1\,W \cdot 8760\ h/a}{1000\ W/kW} \qquad (kWh/a)$$

  $$W_{controller} = (number\ of\ electric\ outputs\ of\ the\ controller) \cdot 8.76 \qquad (kWh/a)$$

9.4 Comments for combisystems

How many controllers to be used:

In the reference boiler, the controller for the heating system and for the boiler is already included. If this controller can be used in the combisystem, it has not to be considered separately.

If the space heating pump is neglected, it has to be neglected also in the combisystem.

10 Literature

DIN 4701, Regeln für die Berechnung der Heizlast von Gebäuden

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Jordan, U., Vajen, K., 2000, Influence of the DHW Load Profile on the Fractional Energy Savings: A Case Study of a Solar Combisystem with TRNSYS Simulations, Solar Energy Vol. 69(Suppl.), Nos. 1-6, pp 197-208, (see also Appendix 1).

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Appendix 1.1, Load Profiles for DHW

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IEA-Task 26, Jan. 2000

Load-Profile on a One-Minute Time Scale

A load profile for the domestic hot water demand for a period of one year was generated. In order to take into account fairly realistic conditions, a **time step of one minute** was chosen. The values of the flow rate and the time of occurrence of every incidence were selected by statistical means.

The basic load is 100 liters/day. The profiles are generated for higher demands in dual order (100, 200, 400, 800 liters ..), with different initial random values. In this way, it is possible to get a load profile for any multi-family house very easily by superposition.

For the IEA-Task 26 simulation studies, a mean load volume of 200 liters per day was chosen for a single family house. Figure A1 shows a three day example for this load-profile.

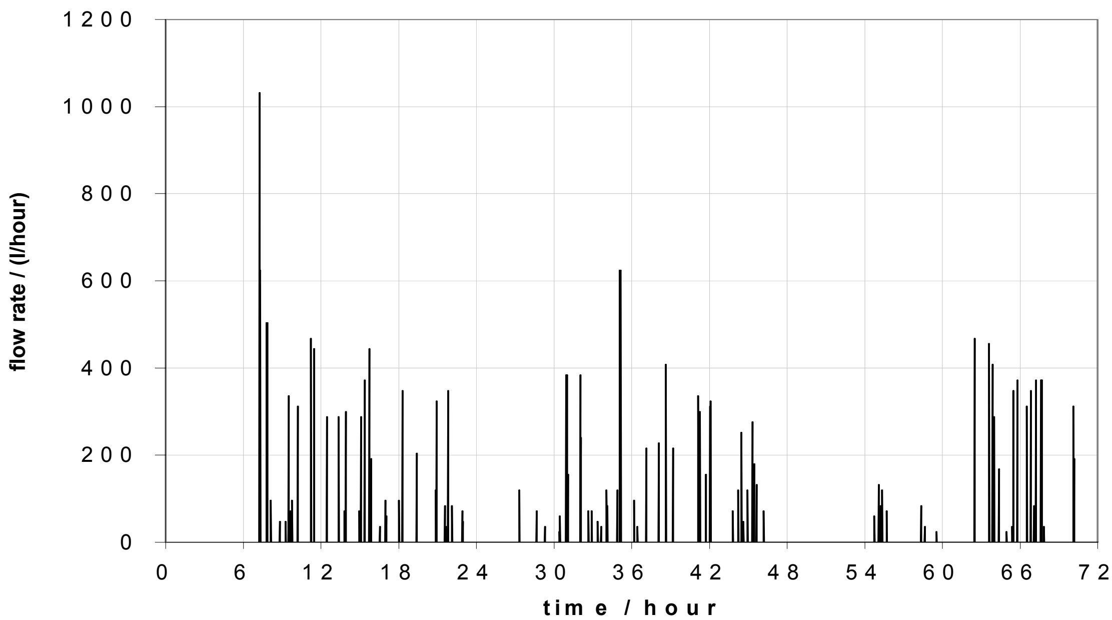


***Figure A1**: Load profile of 72 hours, Jan. 1st – 3rd (200 l/day).*

Basic Assumptions

Four categories of loads are defined. Every category-profile is generated separately and superponed afterwards.

For every category a mean flow rate is defined. The actual values of the flow rates are spread around the mean value with Gauss-Distribution (Figure A2):

$$prob(\dot{V}) = \frac{1}{\sqrt{2\pi\sigma}} \exp \frac{-(\dot{V} - \dot{V}_{mean})^2}{2\sigma^2}$$

The values chosen for σ, for the duration of every load, and for the medium number of incidences during the day are shown in Table A1.

Flow rates in steps of 0.2 l/min = 12 l/h are taken.

A probability function, describing variations of the load profile during the year (also taking into account the (European) daylight saving time), the weekday, and the day is defined for every category.

The Accumulated Frequency Method is used to distribute the incidences described by the probability function among the year.

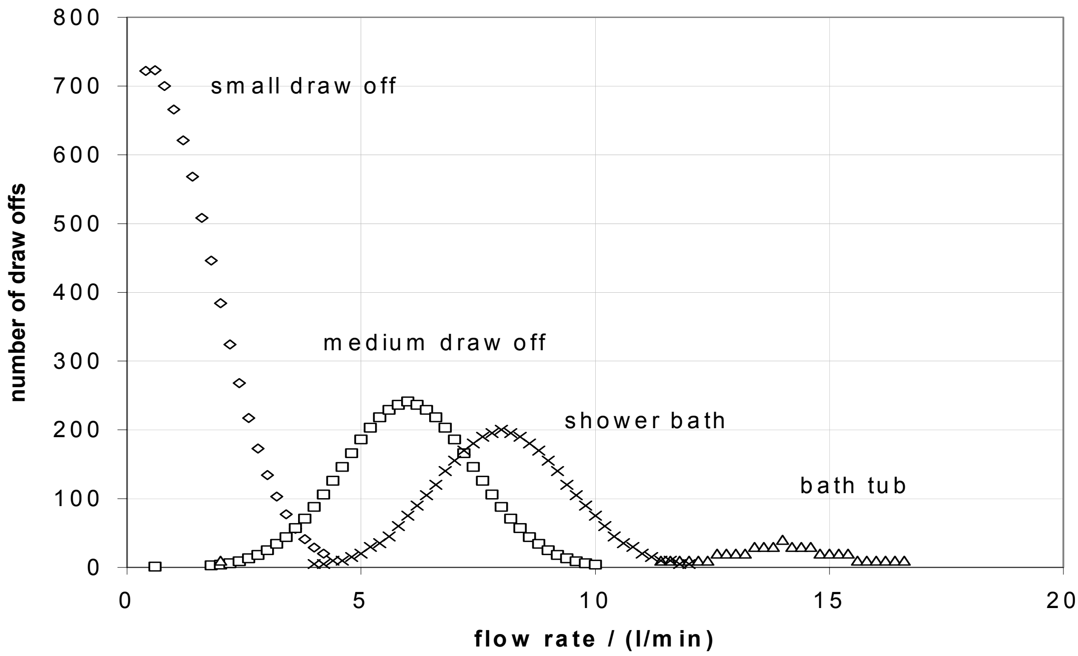


***Figure A2**: Distribution of the values of the flow rates, **discretisation: 0.2 l/min**, total number of incidences (e.g. 702 showers during the year) ⇔ sum of incidences with discrete flow rates.*

The following assumptions are made:

- the mean load is 200 l/day
- four categories to describe the different types of loads are defined:
  cat A: short load (washing hands, etc.)
  cat B: medium load (dish-washer, etc.)
  cat C: bath
  cat D: shower

assumptions made for every specific category
for

- the mean flow rate $\dot{V}$
- the duration of one load duration
- the nr. of incidences (loads) per day inc/day
- the statistical distribution of different flow rates σ

=>

- the mean volume of each load vol/load
- the total volume (for every category) per day vol/day
- portion of volume from the total volume (200 l/day) portion (=^ percentage)

Table A1*: load profile*

	cat A: short load	cat B: medium load	cat C: bath	cat D: shower	Sum
$\dot{V}$ in l/min	1	6	14	8	
duration in min	1	1	10	5	
inc/day	28	12	0.143 (once a week)	2	
σ	2	2	2	2	
vol/load in l	1	6	140	40	
vol/day in l	28	72	20	80	200
portion	0.14	0.36	0.10	0.40	1

The maximum energy of one draw off is:

14 l/min * 10 min * 1.16 Wh/(kgK) * 35 K = 5680 Wh

(suggested max. heat demand according to DIN 4708: P = 5820 Wh)

Table A1 is based on a few research studies about DHW-consumption patterns in Switzerland and Germany, investigated by measurements of the electrical power of el. DHW-burners, measurements of temperatures or flow rates or by a representative telephone research study (e. g. /Loose91/,/Nipkow99/,/Real99/,/Dichter99/).

One-family house: Daily load in the course of the year:

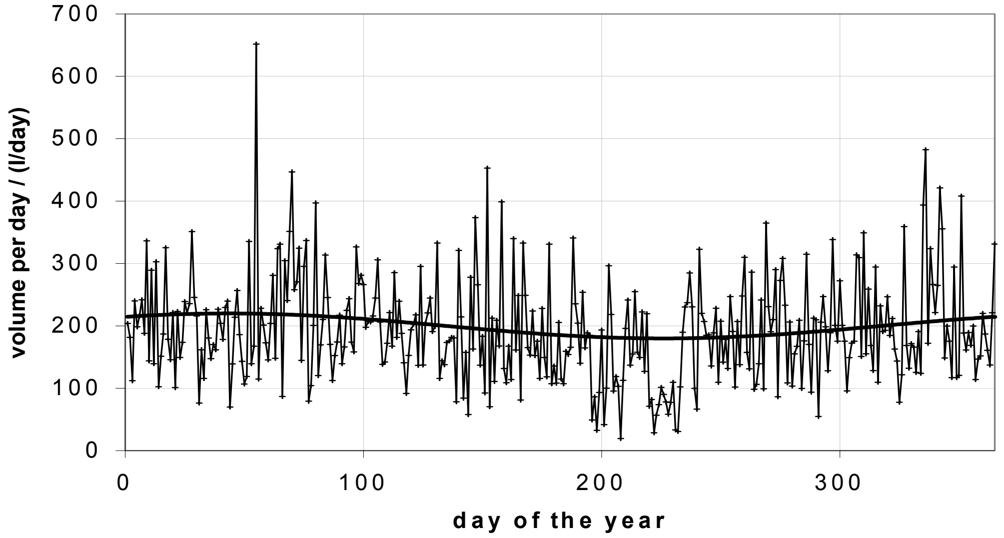


Figure A3*: Distribution of draw-off volume per day during the year (mean value: holidays: 100 l/day, other days: 200 l/day,). The sinus function, used to calculate the probability during the course of the year with an amplitude of 20 l/day is shown with a bold line. Two periods of reduced discharge are taken into account, between Jul. 14th (196. day) and Jul.28th and between Aug. 8th (221. day) and Aug. 22nd .*

Ten-family house: Daily load in the course of the year:

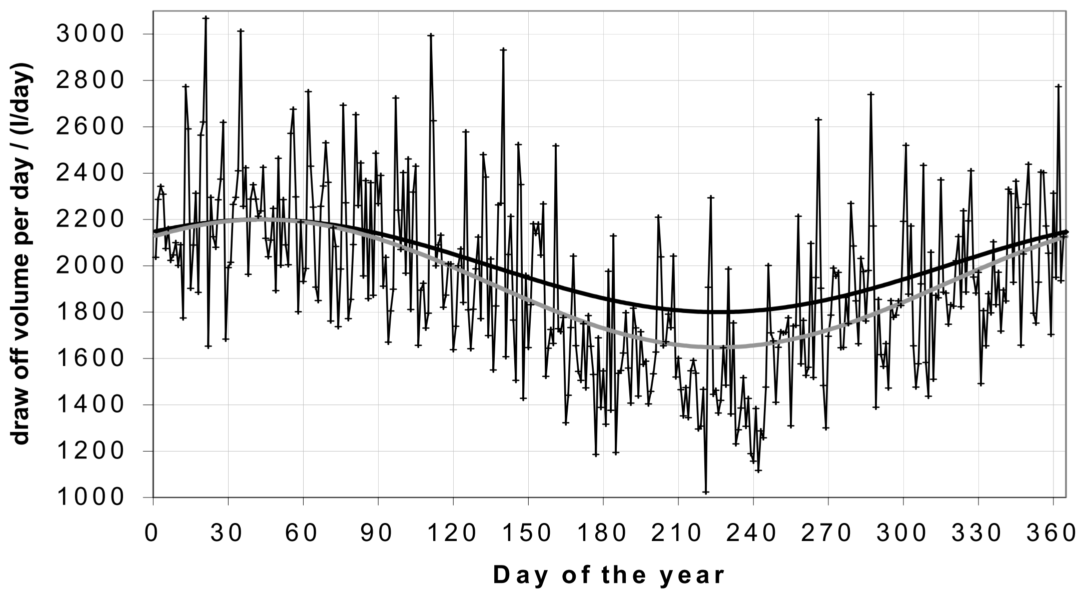


Figure A4*: Distribution of the total draw-off volume per day during the year for a ten-family house (mean value: 2000 l/day). Black line (sinus function): amplitude = 200 l/day (10 %), gray line (sinus function): amplitude = 13.8 %, with 3.8% due to two weeks holidays between June 1^{st} and Sept.30^{th} for every household.*

Probability function

prob = prob(year) * prob(weekday) * prob(day) * prob(holiday)

- The course of probabilities during the year is described by a sinus-function with an amplitude of 10 % of the daily discharge volume (see /Mack98/). **=> *prob(year)***

- The non-equal distribution of DHW-consumption during the weekdays is only applied on the category bath (cat. 3). This was done due to the results of research studies. The probability-function prob(week) for taking a bath (gray columns) and the mean distribution for the total volume per day (black columns) are shown in Figure A5.

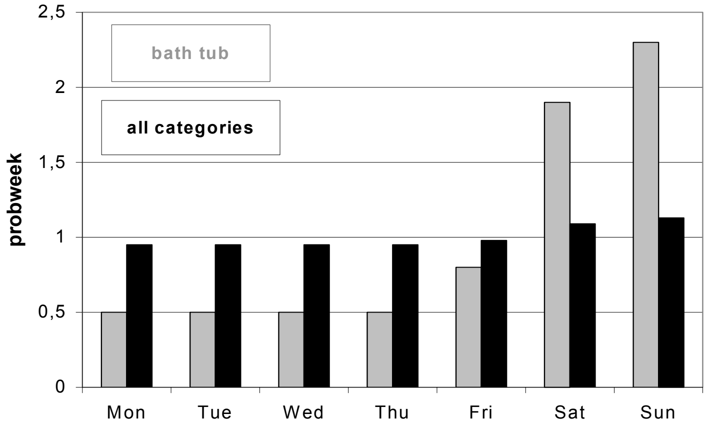
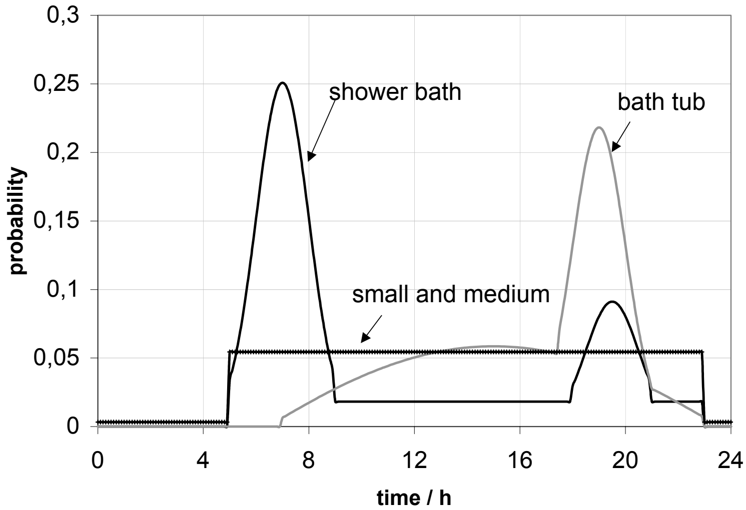


Figure A5*: probability-function <u>only for category 3 (bath)</u>, and mean value of the weekly distribution of all categories (medium load: 100 %, load Mon-Thu: 95 %, Fri: 98 %, Sat. 109 %, Sun.: 113 %).* **=> prob(weekday)**

- The assumptions for the **daily distribution** used, are shown in Figure A6



:

Figure A6*: Probability distribution of the DHW-load in the course of the day. For a short and medium load is distributed equally between 5:00 and 23:00 h.* **=> prob(day)**

- Holidays are taken into account in two ways:

1.) A period of two weeks of no DHW-consumption between June 1st and Sept. 30th is taken into account for a household with a total load of 100 l/day. The starting-day of the holidays is given by a random number. The initialization of the random number generator is set in the way, that the holidays for a one family house with a load of 100 l/day starts at Aug. 1st. For a one family house with a load of 200 l/day (Task26) the DHW-load is reduced by 100 l/day in two periods. The duration of both periods is 2 weeks, starting on Jul. 14th and Aug. 8th, respectively. In multifamily houses the number of reduced DHW-load periods is given by the daily load volume divided by 100 l/day. Therefore, for the multifamiliy house modeled in Task26, 20 periods are taken into account.

2.) The distribution of the DHW-consumption during the year is described by a sinus-function with an amplitude of $\pm$10 % of the average daily discharge volume. This variation takes into account less consumption during the summer than during the winter in general (/Mack98/ found a variation of $\pm$25%, due to variations of the cold water temperature of $\pm$5 K ($\pm$14 %) and variations of the consumption patterns). Due to the two weeks of holidays described in (1.), variations of $\pm$3.8 % are induced.

The probability term in order to describe a load reduction of 100 l for periods of 14 days is given by:

$$prob(holiday) = \frac{mean\ volume\ of\ daily\ load - reduced\ volume}{mean\ volume\ of\ daily\ load}$$

In case of a mean volume of 200 l/day, the possible values for prob(holiday) are

- prob(holiday) = ½ between Jul. 14th .. Jul.28th and Aug. 8th .. Aug. 22nd,
- prob(holiday) = 1 else

If the two periods were overlapping, prob(holiday) would be equal to zero during that period.

The total number of periods with a reduced load is given by the mean volume of daily load/100.

=> yearly volume taken into account:
one-family house 73 000 liter (= 365 days * 200 l/day)
multi-family house 730 000 liter (= 365 days * 200 l/day * 10)

Final Remarks:

The unit of the flow rates is liters/hour.
Format: The new Pascal-format is LongInt, the Trnsys (Fortran)-Format for the DataReader TYPE 9 is (F6.0).

Literature

/Dichter99/ Ernst Dichter: *Dusch- und Badeverhalten. Bericht zu einer Repräsentativumfrage*, Eidgenössische Drucksachen- und Materialzentrale, Bern, 1999.

/Dittrich72/ A. Dittrich, B. Linneberger, W. Wegener: *Theorien zur Bedarfsermittlung und Verfahren zur Leistungskennzeichnung von Brauchwasser-Erwärmern*, HLH 23, Nr. 2, 1972

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/Nipkow99/ Jürg Nipkow: *Warmwasser-Zapfungsverhalten. Schlussbericht.* Industrielle Betriebe der Stadt Zürich, Zürich, 1999. http://www.stadt-zuerich.ch/kap08/energieberatung/s_50.html#Warmwasser-Zapfungsverhalten

/DIN 4702/ *Heizkessel: Ermittlung des Norm-Nutzungsgrades und des Norm-Emissionsfaktors*, Deutsches Institut für Normung

/DIN 4708/ *Zentrale Wassererwärmungsanlagen. (1) Begriffe und Berechnungsmethoden. (2) Regeln zur Ermittlung des Wärmebedarfs von Trinkwasser in Wohngebäuden. (3) Regeln zur Leistungsprüfung von Wassererwärmern in Wohngebäuden.* Deutsches Institut für Normung,

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Superposition of DHW load files:

Pascal program: SUPERP_u.pas

This little program superpones load profiles with the file names: **DHW_Uxxx.txt**.
xxx stands for the mean daily load divided by 100 (e.g. for 200 l/day: DHW_U002.txt).

Therefore, a load profile for up to 999 households with a daily load of 100 l/day each, can be superponed. Up to 14 files may be superponed at one run.
Definitions:

- **Original files** contain load profiles, which are generated with a differently initialized random generator. They have been delivered in dual order: DHW_U001, DHW_U002, DHW_U004, etc.
- **Standard files**: original files and files made by superposition of original files, using every original file no more than once.

In order to superpone profiles, the mean daily load of the files to be superponed needs to be typed in (see example below). The output file will be written into the same directory as the input files. If standard files are created, the output file name will be made automatically.

The output file name needs to be typed in (it should not get the same name as a ‚standard' profile !),

- if ‚non-original' load volumes (e. g. 300 ℓ/d) are used or
- if (for research purposes) the same mean daily load is used more than once.

If identical files are superponed, the output profile may be regarded to be less realistic (‚non-standard file').

When the program is started, the following questions will occur on the screen (answers and commands are written in *italics*). The program shall be started in a DOS-window **in the directory** that contains all input files and the *superp_u.exe*.

Example 1:

c:\path\directory> ***SUPERP_u***
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
100
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
200
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
<return>
Please wait !
10% 20% 40% 50% 70% 80% 90% 100%

Total load during the year = 109500 liters

= 365 days * 300 l/day
New file: DHW_U003.txt

Example 2:

c:\path\directory> ***SUPERP_u***
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
100
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
100
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
100
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
<return>
Two or more identical files will be superponed !
Please type in a new file name (not standard file name) for a file with a load volume of 300 l/day (without path name or extension)
DHW_A003 {e. g. „A“ instead of „U“ !}

Please wait !
10% 20% 40% 50% 70% 80% 90% 100%

Total load during the year = 109500 liters
= 365 days * 300 l/day
New file: DHW_**A**003.txt

Example 3:

c:\path\directory> ***SUPERP_u***
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
300
The given daily load volume does not belong to an original file !

Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
100
Mean daily flow volume (in liters) of the load profile to be superponed ?
(100, 200, 400, 800, 1600), < return >
<return>
Please type in a new file name (not standard file name) for a file with a load volume of 400 l/day (without path name or extension)

DHW_B004 {e. g. „B“ instead of „U“ !}

Please wait !
10% 20% 40% 50% 70% 80% 90% 100%

Total load during the year = 146000 liters
= 365 days * 400 l/day
New file: DHW_**B**004.txt

Appendix 2: Milestone Report C3.1

SHC -TASK 26: SOLAR COMBISYSTEMS

SUBTASK C
MILESTONE REPORT C 3.1
OPTIMIZATION PROCEDURE
(green marks revisions at Experts meeting Rapperswil)
(yellow marks revisions at Experts meeting Oslo)

COMPILED BY W. STREICHER, R. HEIMRATH

OPTIMIZATION PROCEDURE, REFERENCE SYSTEM, PENALTY FUNCTION, TARGET FUNCTION

MAY 03, 2002

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1 Optimization procedure

The optimization procedure for the different systems was defined by a two step approach:
In the first step systems are optimized in itself as they are produced (with their typical collector areas and store volumes).

In the second step the systems are compared to each other by FSC method developed by Letz, Th, 2001, (Appendix 1)

The following steps are performed during the system optimization

- Model the system in TRNSYS for the relevant climate (preferably Zurich) and the 60 kWh/m²a building with collector area and store volumes set by the participant.
- The target functions for the analysis are based on fractional energy savings. Three functions (ref. to chapter 0) have been defined basing on:
  - Final energy for burner (fuel demand),
  - Final energy for burner (fuel demand) including electricity consumption of pumps and boilers
  - Final energy for burner (fuel demand) including electricity consumption of pumps and boilers as well as penalty functions for not fulfilling the comfort criteria's of domestic hot water (DHW) and room temperatures as they are defined for the reference conditions at the Experts Meeting in Helsinki, Oct. 8^{th} – 11^{th}.
- Do a sensitivity analysis (and may be optimization) with this model. The parameters that should be varied are given in **Table 19**. Of course participants can do a sensitivity analysis with more than the mandatory parameters. The model can also be changed, if it is found out, that it is far away from the optimum.
- Optimize the system using the specified target function in chapter 4 (by hand and automatically). If available, cost functions can be included in the optimization.

Besides: do country or company specific calculations

It should be mentioned that each participant does as much as possible within the optimization, but this is of course restricted by funding available for the Task.

The comparison of the different systems is performed by the method developed by Letz, Th, 2001, (Appendix 1) on the basis of theoretically maximum fractional savings and actual achieved fractional savings. At least all climates and buildings (MFH is optional) should be calculated using the values listed in the last column of Table 1. Of course additional simulations (e.g. variations of collector area and store volumes) can be carried out.

As result of this analysis recommendations and general guidelines for advanced solar combisystems can be drawn and elements of "dream" combisystems can be defined.

Open and fixed Parameters

The parameters to be included in the optimization are defined as shown in **Table 19**.

***Table 19**: Parameters for optimization (values, boundaries and fixed parameters see Milestone Report C 0.2, Reference Conditions)*

		Ref.-Cond	Analysis/Optimization	Comparison
Climate	**Four Climates** Stockholm (northern Europe) Zürich (middle Europe) Carpentras (southern Europe)	 * * *	One	All
Load	Space Heating System **a) One family house** **100 kWh/m²a** **60 kWh/m²a** **30 kWh/m²a** b) Multiple family house (45 kWh/m²a) c) Lay-Out temp. of heating system [°C]	* * * * *	One ? if possible fixed	All ? fixed
System	**Collector** Type (η_0, a_1, a_2) (2 types in ref. cond.) Area [m²] Azimuth (-90 - +90°) Tilt angle (0 – 90°) Specific flow rate (kg/m²h) (8 – 50 l/m²h) Fixed/matched flow	*	One variable fixed fixed fixed fixed	? fix (categ.?)[1] fixed (0) fixed (45) fixed fixed flow
	Pipe system (collector – storage unit) electricity consumption (pump) [W]			fixed
	Storage Unit(s) Volume [m³] Volume/diameter [m³/m] Position of heat exchangers Position of in/outlets Fixed position of in/outlets – stratification unit Position of sensors Thermal insulation [W/m²K]		Free discussion for each System	fix (categ.?)[1] opt. fixed opt. fixed opt. fixed opt. fixed opt. fixed opt. fixed
	DHW – preparation Load Circulation loop (if necessary) Length of circul. Loop [m] Heat loss (thermal insulation) [W/K] Electricity consumption (pump) [W]	*	fixed none none fixed fixed	fixed (ref) none none fixed fixed
	Heat exchangers U*A [W/K]		variable	opt. fixed
	Control Strategy		variable	opt. fixed
	Auxiliary heating Range of modulation (if possible) Fuel consumption (e.g. wood, gas) Electricity consumption (pump, control-unit)	*	?	fixed

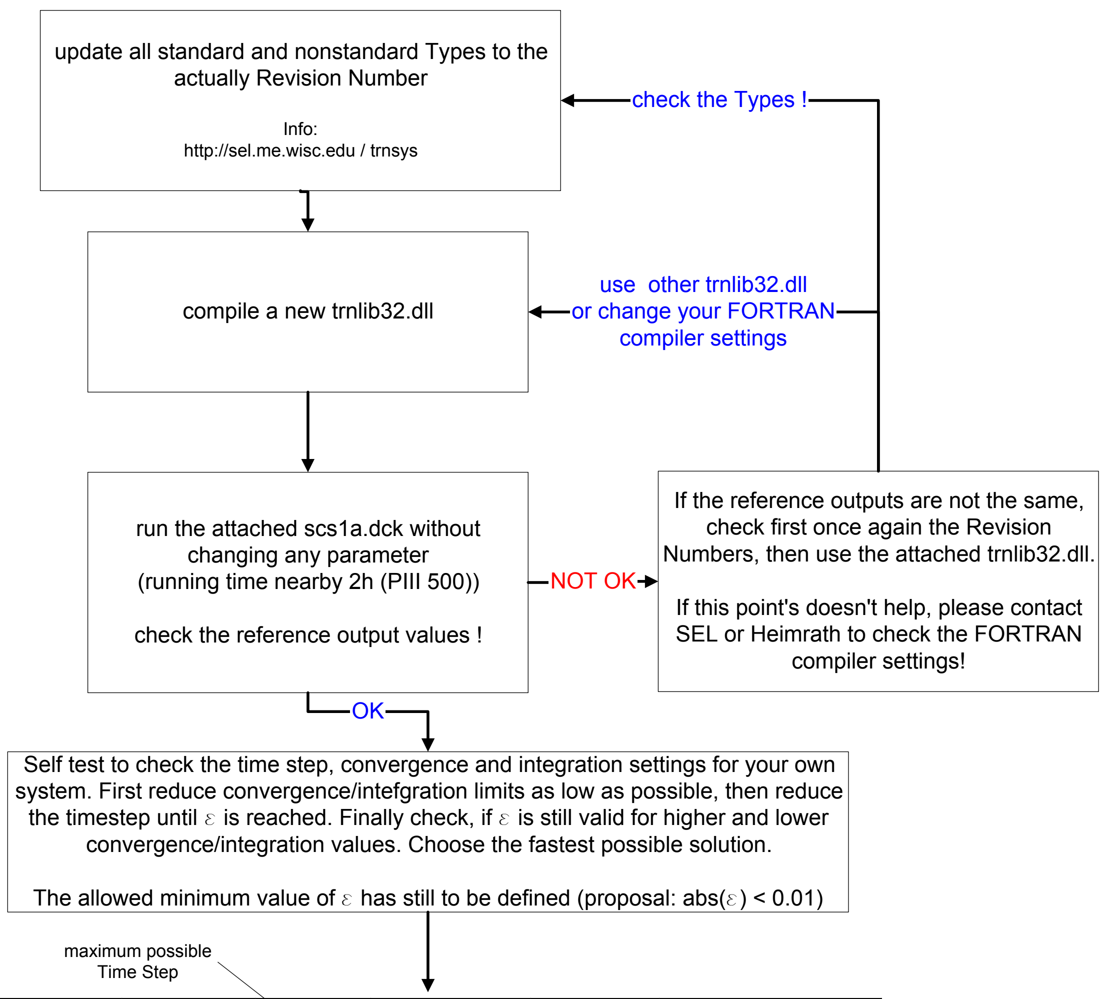
opt. fixed: optimum from system analysis/optimization taken.

1) preferably the same collector area and storage volume for the different locations. Otherwise the values have to be explained

Parameters to be checked by everybody before performing the sensitivity analysis

1) all TRNSYS TYPES used are the same for all participants (all current TYPES are collected at the TRNSYS website, i.e. the part accessible for Task 26 workers http://sel.me.wisc.edu/TRNSYS/Downloads/IEA26/IEA26.htm
2) Simulation time step
3) relative and absolute accuracy (of dck) (see **Fig. 1**)
4) Number of store layers (watch for sensor positions)

The following proposal of Heimrath, R., in Fig. 1 for this procedure was agreed on :



maximum possible Time Step

Parameter			Results (example)		
Convergence	Integration	Time Step	simulation runs	$f_{save,therm}$	$\varepsilon=(f_s(i)-f_s(i-1))/f_s(i-1)$
0.10	0.10	1/20	yes	0.25	
0.01	0.01	1/20	yes	0.24	-0.051
0.01	0.01	1/20	yes	0.23	-0.025
0.00	0.00	1/20	no	-	-
0.01	0.01	1/20	yes	0.23	
0.01	0.01	1/32	yes	0.23	-0.017
0.01	0.01	1/40	yes	0.23	-0.013
0.01	0.01	1/64	yes	0.23	-0.01
0.01	0.01	1/64	yes	0.23	0.01
0.00	0.00	1/64	yes	0.22	0.00

Convergence and Integration values are not possible

ε < 0.01

choosen values ε < 0.01, short simul. time

Last convergence/ integration check (both compared to 0.005;0.005;1/64)

Fig. 1 *Proposal for the simulation procedure to ensure the same TRNSYS TYPES and the same accuracy.*

2 Reference DHW- and SH-System

Major inputs from:

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Jaehnig, D., SOLVIS, Braunschweig, Germany
Papillon, Ph, Clipsol, Trevignin, France
Streicher, W., IWT TU-Graz, Austria

The solar combisystems are not only compared with each other but additionally against a conventional reference system without a solar plant. This reference system is used also for the optimization with the target functions (chapter 4). The reference system is described in the following.

2.1 General approach for the primary energy demand of the reference system

The values of the reference system are calculated according to the following approach (taking into account the stand-by electricity demand):

$$Q_{ref,pri} = \frac{Q_{burner,ref}}{\eta_{burner}} + \frac{W_{ref}}{\eta_{el}} = \frac{Q_{SH} + Q_{DHW} + Q_{l,ref}}{\eta_{burner}} + \frac{W_{ref}}{\eta_{el}} \qquad \text{(kWh/a)}$$

As a gas burner is assumed for the reference system the burner efficiency is set to $\eta_{burner,gas}$ = 85 % according to Milestone Report C 0.2, chapter 5. the efficiency of the electricity production is set to η_{el} = 40 %

2.2 Final Space heating Q_{SH} and DHW Energy Q_{DHW} of the Reference System

The energy demands for space heating (Q_{SH}) and domestic hot water production (Q_{DHW}) of the reference system are calculated in TRNSYS for the reference buildings and climates, assuming a radiator heating system and an ideal burner. Table 20 shows the calculated values for Q_{SH} and Q_{DHW} of the reference systems. Additionally the specific space heating demand $Q_{SH,spec}$ is shown.

Table 20 *Space heating Q_{SH} and DHW energy Q_{DHW} of the reference system (11/2001)*

	Q_{SH} [kWh/a]				Q_{DHW} [kWh/a]	
	SFH 30	**SFH 60**	**SFH 100**	**MFH 45**	**SFH**	**MFH**
Carpentras	1565	3587	6925	9320	2723	13568
Zurich	4319	8569	14283	22543	3040	15208
Stockholm	6264	12227	19773	31850	3122	15656
	$Q_{SH,spec}$ [kWh/m²a]					
Carpentras	11.2	25.6	49.5	18.6		
Zurich	30.9	61.2	102.0	45.1		
Stockholm	44.7	87.3	141.2	63.7		

2.3 Reference Storage Heat Loss

For the reference system no heat-store for space heating is assumed. The yearly heat loss of the DHW-storage of the reference system $Q_{l,ref}$, is given by:

$$Q_{l,ref} = (UA)_{S,ref} \cdot (T_S - T_{S,amb}) \cdot 8760\,h \qquad \text{(kWh/a)}$$

The size of the store, $V_{S,ref}$, is defined as 0.75 times the daily DHW-discharge volume (in liters), with the heat loss rate: $(UA)_{S,ref} = 0.16\sqrt{V_{S,ref}}$ in W/K (prENV 12977-1:2000).

With a storage temperature of 52.5°C and a daily load volume of 200 ℓ with a temperature of 45°C, $Q_{l,ref}$ turns out to 644 *kWh:*

SFH: $Q_{l,ref} = 0.16\sqrt{0.75 \cdot 200}\,\frac{W}{K} \cdot (52.5 - 15)K \cdot 8760h = 644 \qquad (kWh/a)$

MFH: $Q_{l,ref} = 5 \cdot 0.16\sqrt{0.75 \cdot 200}\,\frac{W}{K} \cdot (52.5 - 15)K \cdot 8760h = 3220 \qquad (kWh/a)$ (04/2002)

Attention: check the $T_{basement}$=15 °C in your Type 140 (hot water store)

Using the SH-demand, DHW-demand, the reference storage heat loss and the burner efficiency the final heat energy demand can be calculated for the reference system.

***Table 21** Final heat energy demand of the reference system $Q_{burner,ref}/\eta_{burner}$ (11/2001 04/2002)*

$Q_{burner,ref}/\eta_{burner}$	SFH 30	SFH 60	SFH 100	MFH 45
	[kWh/a]			
Carpentras	5802	8180	12107	31789
Zurich	9414	14415	21137	49971
Stockholm	11800	18784	27693	61635

2.4 Total final electrical energy demand of the reference system

The following assumptions are made for this calculation:

- The circulation pump for the space heating system is included in the burner
- The electricity demand for boiler operation and for standby are taken from Milestone Report C 0.2, Reference Conditions with $P_{el,on}$ = 35 W and $P_{el,stby}$ = 9 W.
- The pump to fill the DHW tank has to be calculated extra ($P_{el,pump,DHW}$ = 60 W according to Milestone Report C 0.2, Reference Conditions)

Table 22-Table 24 show the calculated electricity primary energy demand, the running time of the space heating pump (calculated with Type 135, Papillon, 2000) primary energy demand of the reference system $Q_{ref,pri}$ for all buildings and climates.

running time of the pumps:

$$\Delta t_{bur-on,ref} = \frac{Q_{SH} + Q_{DHW} + Q_{l,ref}}{P_{burner}} \qquad (h)$$

$$\Delta t_{DHW} = \frac{Q_{DHW} + Q_{l,ref}}{P_{burner}} \qquad (h)$$

Nominal burner power and seasonal efficiency (gas burner for reference system)

⇨ **SFH:** $P_{burner} = 15\,kW, \quad \eta_{burner} = 0.85$ (ref. Milestone Report C 0.2)

⇨ **MFH:** $P_{burner} = 24\,kW, \quad \eta_{burner} = 0.85$ (ref. Milestone Report C 0.2)

⇨ **Electricity production:** $\eta = 0.40$ (agreed on by all participants)

$$W_{bur,ref} = P_{el,on} \cdot \Delta t_{bur-on,ref} + P_{el,stby} \cdot \left(8760 - \Delta t_{bur-on,ref}\right) \qquad (kWh/a)$$

⇨ $$W_{bur,ref} = \Delta t_{bur-on,ref} \cdot \left(P_{el,on} - P_{el,stby}\right) + 8760 \cdot P_{el,stby} \qquad (kWh/a)$$

$$W_{bur,ref} = \frac{Q_{SH} + Q_{DHW} + Q_{l,ref}}{P_{burner}} \cdot \left(P_{el,on} - P_{el,stby}\right) + 8760 \cdot P_{el,stby} \qquad (kWh/a)$$

$$W_{el,pump,DHW,ref} = \Delta t_{DHW} \cdot P_{el,pump,DHW}$$

⇨ $$W_{el,pump,DHW,ref} = \left(\frac{Q_{DHW} + Q_{l,ref}}{P_{burner}}\right) \cdot P_{el,pump,DHW}$$

⇨ $$W_{ref} = W_{bur,ref} + W_{el,pump,DHW,ref}$$

⇨ $$Q_{ref,pri} = \frac{Q_{burner,ref}}{\eta_{burner}} + \frac{W_{ref}}{\eta_{el}} = \frac{Q_{SH} + Q_{DHW} + Q_{l,ref}}{\eta_{burner}} + \frac{W_{ref}}{\eta_{el}}$$

Table 22 *Primary Energy Demand for electricity of the Reference System W_{ref}/η_{el} (11/2001 04/2002)*

	SFH 30				SFH 60			
	W_{BURNER}/η_{el}	W_{DHW}/η_{el}	W_{SH}/η_{el}	W_{TOTAL}/η_{el}	W_{BURNER}/η_{el}	W_{DHW}/η_{el}	W_{SH}/η_{el}	W_{TOTAL}/η_{el}
	[kWh/a]				[kWh/a]			
Carpentras	218.5	30.86	686.8	936.0	227.2	30.86	903.0	1161
Zürich	231.8	33.76	1122	1388	250.2	33.76	1211	1495
Stockholm	240.6	34.52	1239	1514	266.2	34.52	1353	1654

	SFH 100				MFH 45			
	W_{BURNER}/η_{el}	W_{DHW}/η_{el}	W_{SH}/η_{el}	W_{TOTAL}/η_{el}	W_{BURNER}/η_{el}	W_{DHW}/η_{el}	W_{SH}/η_{el}	W_{TOTAL}/η_{el}
	[kWh/a]				[kWh/a]			
Carpentras	241.7	30.86	1142	1414	290.0	104.9	1015.8	1410.7
Zürich	275.0	33.76	1298	1606	343.1	115.2	1256.4	1714.6
Stockholm	299.1	34.52	1417	1750	377.2	118.0	1391.3	1886.4

Table 23 *Running Time Space Heating Pump [h] (11/2001)*

	SFH 30	SFH 60	SFH 100	MFH 45
	[h]			
Carpentras	2954	3884	4911	4277
Zürich	4828	5207	5581	5289
Stockholm	5328	5821	6094	5857

Table 24 *Primary Energy Demand of the Reference System $Q_{ref,pri}$ (11/2001 04/2002)*

$Q_{ref,pri}$	SFH 30	SFH 60	SFH 100	MFH 45
	[kWh/a]			
Carpentras	6738	9342	13521	33200
Zurich	10802	15909	22743	51686
Stockholm	13313	20438	29444	63522

3 Penalty function

Major inputs from:

Heimrath, R., IWT TU-Graz, Austria
Jaehnig, D., SOLVIS, Braunschweig, Germany
Jordan, U., Uni Marburg, Germany
Vajen, K., Uni Marburg, Germany
Streicher, W., IWT TU-Graz, Austria

Although many reference conditions are fixed, a final check has to be made, if the solar combisystem is capable in fulfilling the user demand of SH and DHW. Therefore so called 'penalty functions' for DHW and SH are defined. If the temperature needed for DHW (45°C) is not reached within a time step, an additional energy demand, the penalty, is calculated and interpreted as auxiliary heat demand in the fractional savings indicator (see chapter 0). In the same way a temperature below 19.5 or above 24°C in the building is calculated as a penalty energy demand.

The penalty value is the sum of DHW+SH penalty. It is used only used for the optimization and for the internal comparisons.

$$Q_{penalty,solar,red} = Q_{penalty,SH,solar,red} + Q_{penalty,DHW}$$

Nomenclature:

ΔM	mass flow per time step
Δt	time step of simulation
c_p	specific heat coefficient
$\dot{M}$	mass flow
P	power (thermal and electrical)
Q	thermal energy
t	time
T	temperature
$UA_{building}$	heat loss coefficient of the building
W	electrical energy
η	efficiency

Indices:

DHW	domestic hot water
el	electrical devices
l	heat loss
pri	primary energy
ref	conventional reference system

room	room
SH	space heating
solar	solar combisystem system
step	time step of simulation

3.1 Penalty function for DHW demand

The Penalty function for DHW is an exponential term based on the DHW temperature including the energy not delivered to the user (see also Fig. 2).

$dQ_{penalty}$ = dM * cp * {[(Max(0;(45-T_{DHW}))+1)^x-1] + Max(0;(45-T_{DHW}))} *(kWh/step)*

$$Q_{penalty,DHW,\Delta t} = \Delta t \cdot \dot{m} \cdot c_p \cdot \left[\left\{\left(MAX\left(0,\left(45-T_{DHW}\right)\right)+1\right)^X - 1\right\} + MAX\left(0,\left(45-T_{DHW}\right)\right)\right] \textit{(kWh/step)}$$

$$Q_{penalty,DHW} = \sum_{1}^{nr\ of\ timesteps} Q_{penalty,DHW,\Delta t} \quad \textit{(kWh/a)}$$

The exponent used is in minimum **4**; higher ones are possible

Penalty function of the reference system for DHW:
The penalty function for DHW system for the reference system is set to 0. The reference system should deliver all the heat needed anyway.

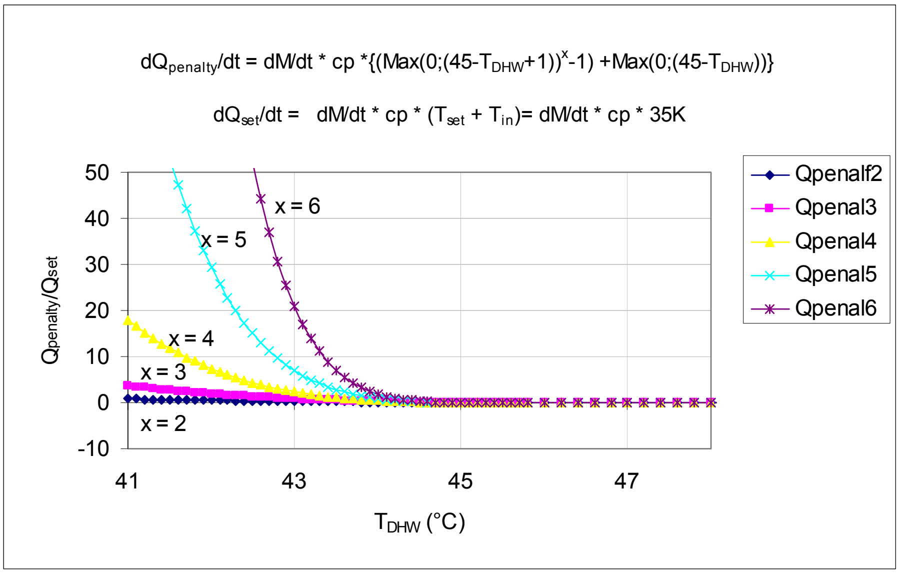


Fig. 2 *Penalty function for DHW-temperature.*

3.2 Penalty function for space heat demand

The penalty function for the space heating system is similar to that of the DHW demand and references to the room temperature. It additionally gives a penalty, if the room temperature is above 24°C. Fig. 3 shows the function

Temperatures below 19.5°C

$$Q_{penalty,SH,\Delta t,19.5} = (UA)_{building} \cdot \Delta t \cdot MAX\left[0;\left(\left(MAX\left(0;(19.5°C - T_{room} + 1)\right)^x - 1\right) + MAX\left(0;(19.5°C - T_{room})\right)\right)\right]$$

(kWh/step)

Temperatures above 24°C

$$Q_{penalty,SH,\Delta t,24} = (UA)_{building} \cdot \Delta t \cdot MAX\left[0;\left\{\left(MAX\left(0;(T_{room} - 24°C + 1)\right)^{x} - 1\right)\right\}\right] \quad \textit{(kWh/step)}$$

No penalty between 19.5 and 24°C

$$Q_{penalty,SH,i} = \sum_{1}^{nr\ of\ timesteps} Q_{penalty,SH,\Delta t,i} \quad \textit{(kWh/a)}$$

The exponent was chosen with **2** to get a first experience with the SH-penalty function.

$(UA)_{building}$: heat capacity rate of the room to be heated is given in each building Zurich climate, there is no change to other climates, see Table 25

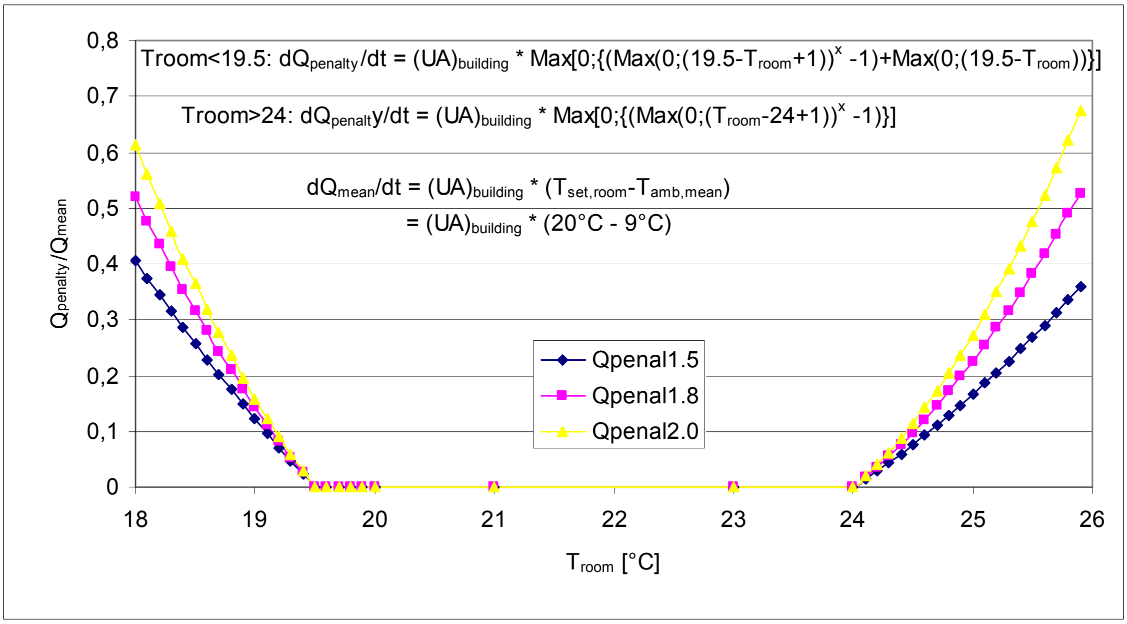


Fig. 3 Penalty functions for room-temperature.

Penalty function of the reference system for SH:
The space heating penalty function was calculated for the reference case for each building and climate (ref. Table 25). It consists of a (zero) penalty for the heating case (t_{room} < 19.5°C) and a high value of summer overheating (t_{room} > 24°C). The penalty function of the solar heating system will be subtracted by the penalty function of the reference case. So the overheating problem due to passive solar gains is eliminated.

Table 25: Penalty functions for space heat demand and the UA-values for the reference buildings (10/2001)

	SFH 30	SFH 60	SFH 100	MFH 45
	Qpenalty,SH,reference,24 [kWh/a]			
Carpentras	27338	31807	28129	39312
Zurich	7101	6208	3766	5624
Stockholm	6247	5091	2453	4065
	Qpenalty,SH,reference,19.5 [kWh/a]			
Carpentras	0.00	0.00	0.00	0.00
Zurich	0.00	0.00	0.40	0.00
Stockholm	0.00	0.00	2.00	0.00
	UA-value W/K			
	94.33	165.00	243.00	465.67

$$Q_{penalty,SH,solar,red,24} = Q_{penalty,SH,solar,24} - Q_{penalty,SH,reference,24} \quad (kWh/a)$$

$$Q_{penalty,SH,solar,red,19.5} = Q_{penalty,SH,solar19.5} - Q_{penalty,SH,reference,19.5} \quad (kWh/a)$$

$$Q_{penalty,SH,solar,red} = Q_{penalty,SH,solar,red,24} + Q_{penalty,SH,solar,red,19.5} \quad (kWh/a)$$

4 Target Functions

Major inputs from:

Bales, Ch., SERC, Borlänge, Sweden
Bony, J, EIVD, Yverdon-les-Bains, Switzerland
Heimrath, R., IWT TU-Graz, Austria
Jordan, U., Uni Marburg, Germany
Letz. Th. ASDER, Saint Alban-Leysse, France
Papillon, Ph, Clipsol, Trevignin, France
Suter, J.-M. N+1, Bern, Switzerland
Streicher, W., IWT TU-Graz, Austria

The target function for the optimization is based on fractional energy savings f_{sav}. According to CEN/TC 312, ISO/TC 180, f_{sav} is related to the purchased auxiliary energy. Three types of functions are used in TASK 26.

- **fractional thermal energy savings ($f_{sav,therm}$)**

This definition gives fractional energy savings based on the saved fuel input of the solar combisystem compared to the reference heating system

- **extended fractional energy savings ($f_{sav,ext}$)**

In this definition the above value is extended by the electricity savings of the solar combisystem. $f_{sav,ext}$ can be used for outside communication, for example in the brochure or the design handbook.

- **fractional savings indicator (f_{si})**

This last definition includes also the penalty function of the solar combisystem in the fractional energy savings. This definition is only used for optimization, ranking and internal comparisons.

As the non-standard TRNSYS TYPE 170 is used for the burner simulation the following OUTPUTS of the TYPE can be used for the calculations:

$Q_{burner,solar}$: OUTPUT 13 of TYPE 170
$\eta_{burner,solar}$: OUTPUT 20 of TYPE 170
$Q_{burner,solar}$ / $\eta_{burner,solar}$: OUTPUT 6 of TYPE 170

In the following the mathematical descriptions of the three definitions of fractional energy savings are shown:

(fractional thermal energy savings)

$$f_{sav,therm} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}}} = 1 - \frac{output\ 6\ of\ type\ 170}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}}}$$

(extended fractional energy savings)

$$f_{sav,ext} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}} + \dfrac{W_{solar}}{\eta_{el}}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}} + \dfrac{W_{ref}}{\eta_{el}}} = 1 - \frac{output\ 6\ of\ type\ 170 + \dfrac{W_{solar}}{\eta_{el}}}{Q_{ref,pri}}$$

(fractional savings indicator)

$$f_{si} = 1 - \frac{\dfrac{Q_{burner,solar}}{\eta_{burner,solar}} + \dfrac{W_{solar}}{\eta_{el}} + Q_{penalty,solar,red}}{\dfrac{Q_{burner,ref}}{\eta_{burner,ref}} + \dfrac{W_{ref}}{\eta_{el}}} = 1 - \frac{output\ 6\ of\ type\ 170 + \dfrac{W_{solar}}{\eta_{el}} + Q_{penalty,solar,red}}{Q_{ref,pri}}$$

5 Literature

prENV 12977-1:2000 ,Thermal solar systems and components – Custom built systems – Part1: General requirements.

Appendix 2.1: Combisystem characterisation

Combisystem characterisation

Thomas Letz - ASDER
March 27, 2001

ASDER

1 Solar resources and load, fractional solar consumption

For combisystems more than for Solar Domestic Hot Water systems, load and solar resources are shifted about 6 months. The two following diagrams show this phenomenon.

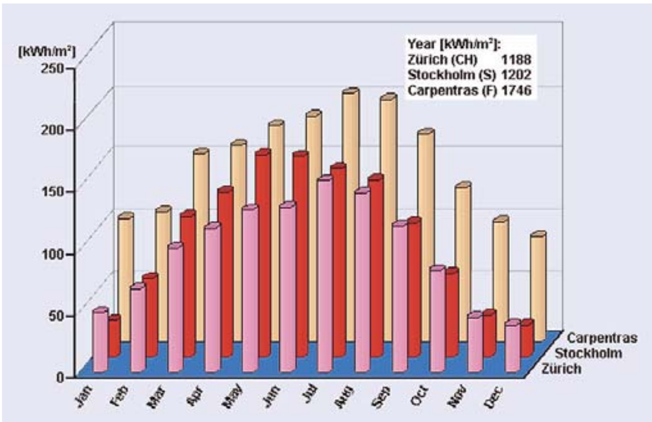


Diagram 1: monthly values of the solar irradiation on a South facing plane with a tilt angle equal to the latitude [1]

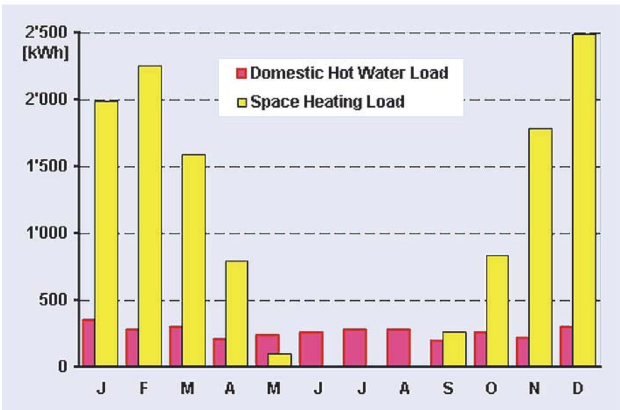


Diagram 2 : an example of seasonal variations of the (measured) heat demand for space heating and DHW in a well insulated building in France [1]

Functioning and performances of a combisystem are strongly correlated with these two parameters. However, in order to simplify the presentation and the visualisation of performances, it would be nice to have a presentation related to only **one** parameter, that could integrate the two parameters. The following parameter, called **Fractional Solar Consumption (FSC)** can play this role. It represents the proportion of energy consumptions for space heating and DHW which are "in phase" with available solar energy.

$$FSC = \frac{\sum_{1}^{12} \min(\mathrm{Cons}_{\mathrm{ref}}, \mathrm{A}\,.\,\mathrm{H})}{\sum_{1}^{12} \mathrm{Cons}_{\mathrm{ref}}} \qquad (1)$$

où : **Cons$_{ref}$** is the monthly reference consumption without solar combisystem (kWh).
A is the solar collector area (m²)
H is the monthly global irradiation in the collector plane (kWh/m²)

Diagram 3 illustrates the definition of FSC : $FSC = \dfrac{\boxed{\cdot\ \cdot}}{\boxed{\cdot\ \cdot} + \boxed{\cdot\ \cdot}}$

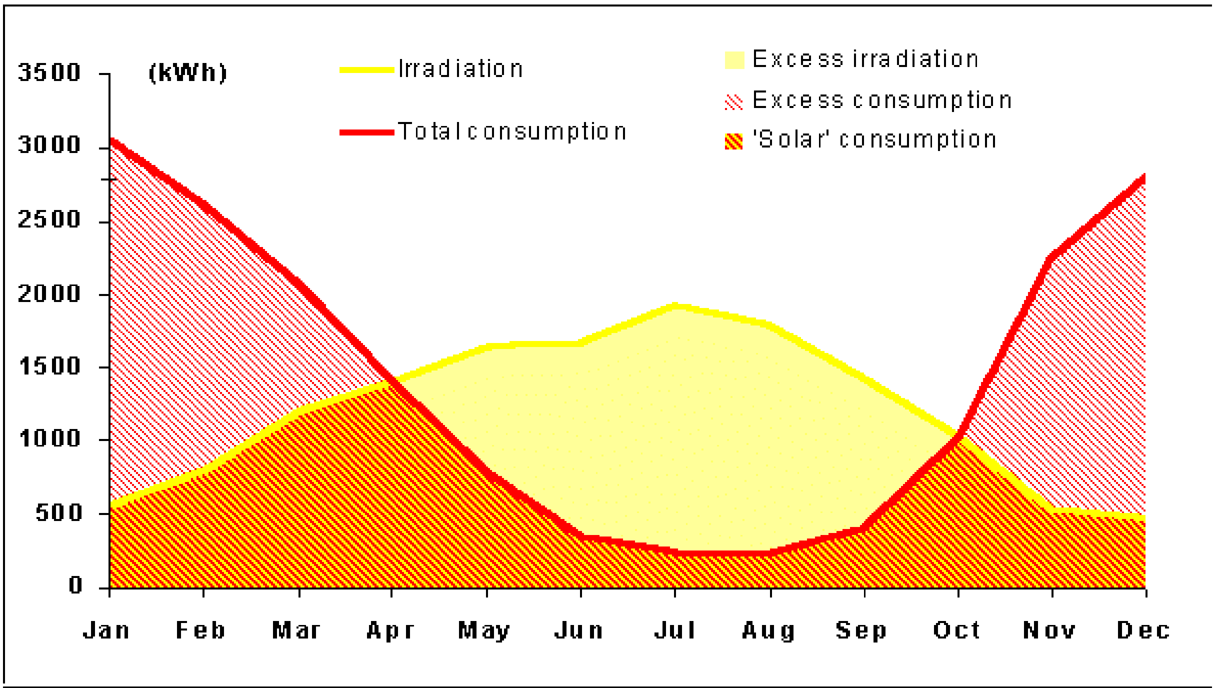


Diagram 3 : definition of the fractional solar consumption FSC

By definition, FSC is below 1. A high value of FSC indicates that the combisystem tends to be oversized. For a collector area equal to 0, obviously FSC is also equal to 0.

N.B. : This approach can only be used for combisystems with a space heating storage sized for some days. Systems with inter-seasonal storage cannot be represented with this approach, since the principle is to shift the excess summer solar irradiation to the wintertime.

2 Relation Fsav = f(FSC). Typical coefficients

First application

In the Helsinki meeting, I presented an effectiveness diagram :
Fsav related to the ratio Irradiation on collector . collector area / SH load.

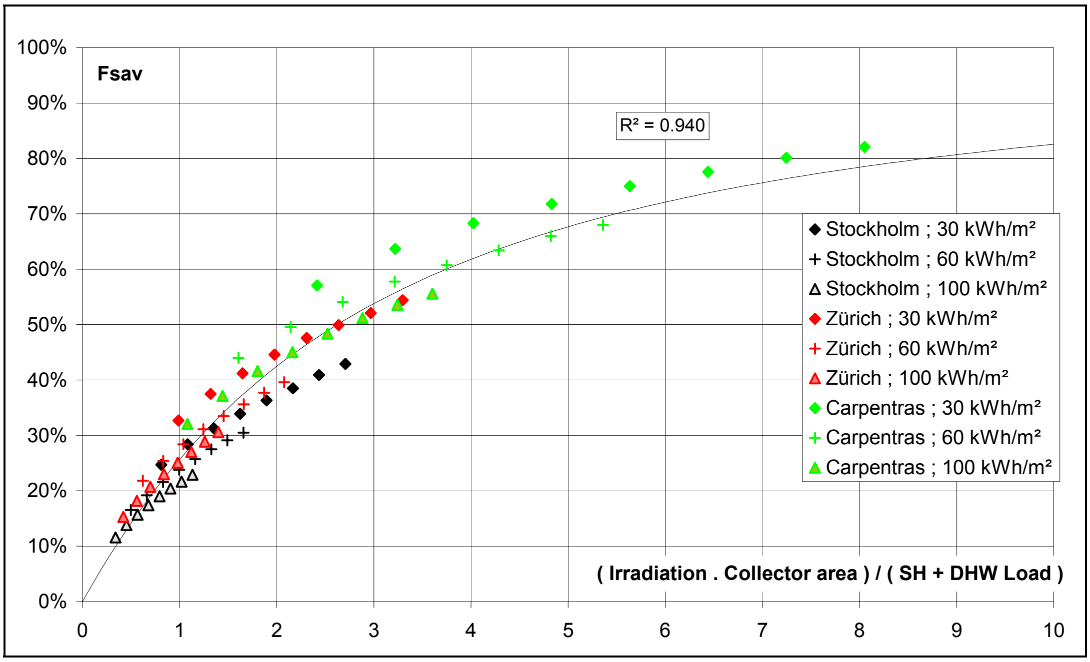


Diagram 4 : effectiveness diagram

It can be seen that points are scattered, and correlations are obvious only when a climate and a SH load are fixed. From such a diagram, it is difficult to give a curve which can characterise the system.

But if we plot F_{sav} according to FSC, with the same conditions as in diagram 4 , we obtain diagram 5.

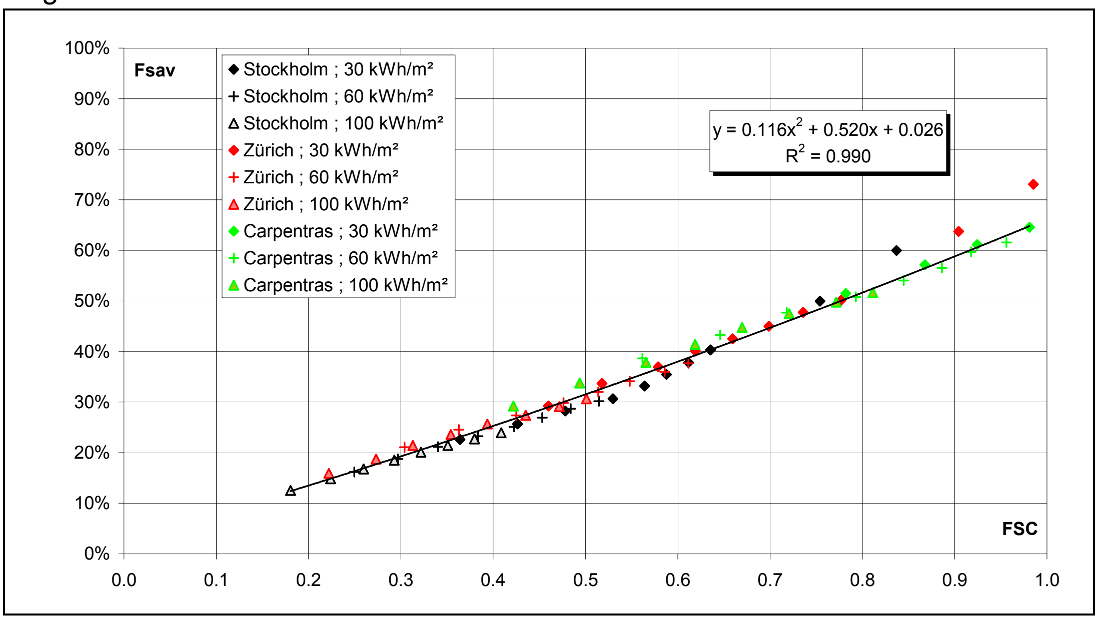


Diagram 5 : diagram fractional energy savings according to FSC

Points can be adjusted by a second order polynomial, with a determination factor equal to 99 %. This adjustement is noteworthy, taking into account the large range of parameters, especially the two first :

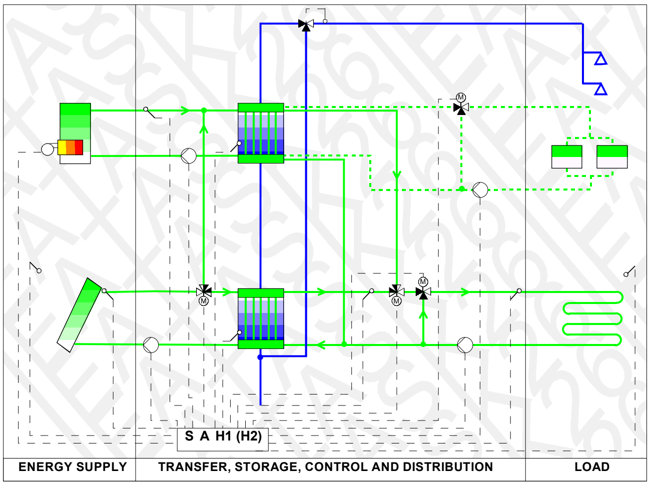
1. Space heating load between 1680 and 18000 kWh
2. Global irradiation between 1220 à 1750 kWh/year.m²
3. DHW load between 2660 à 3100 kWh

The parabola portion seems to be a system characteristic. However, in the previous example, the DHW load fits to a 200 liter/day consumption, identical for all simulations. Now we will study if the proposed formulation allows to take into account various DHW consumptions.

Generalisation

For the first validation of this new concept, we used two different combisystems :

1. a Direct Solar Floor : it is the system n°3 of the coloured booklet [1]. This system is equipped with 2 tanks for DHW, the size of them (250 l) does not depend from the size of the solar collector
2. a Tank in Tank combisystem : it is the system n°9 of the coloured booklet [1]. For this system, we chose a ratio for the storage tank equal to 75 l/m² solar collector, with a 200 l storage inside for DHW.



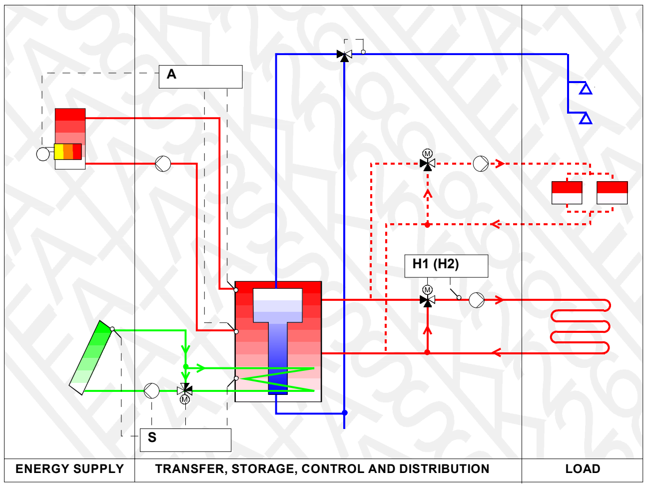


Diagram 6 : diagrams of the simulated systems : Direct Solar Floor, Tank in Tank

Many simulations have been realised with the software PSD-MI [4] for the first system and with the software Polysun [5] for the second one. In the first case, reference consumptions have been calculated with efficiency values integrated in the method. These values fit with the French Thermal Regulation Th-C of 1989 [6]. For the second case, as the Polysun software does not take into account the efficiency of the auxiliary boiler, we assumed an efficiency equal to 85 %, according to recommendations given in document [3]. As reference parameters differ in both calculation methods, the results must not be compared between both systems. The important point is the shape of the curves and the scattering of the points on each diagram.

For each combisystem, 135 calculations have been made for :

1. 3 climates : Stockholm, Zürich and Carpentras
2. 3 individual house (SFH 30, SFH 60 and SFH 100)
3. 3 DHW consumption : 100, 200 and 400 litres per day
4. 5 solar collector sizes : 5, 10, 15, 20 and 30 m².

If we plot the curve F_{sav} = f (FSC) for the first system, we obtain the following diagram :

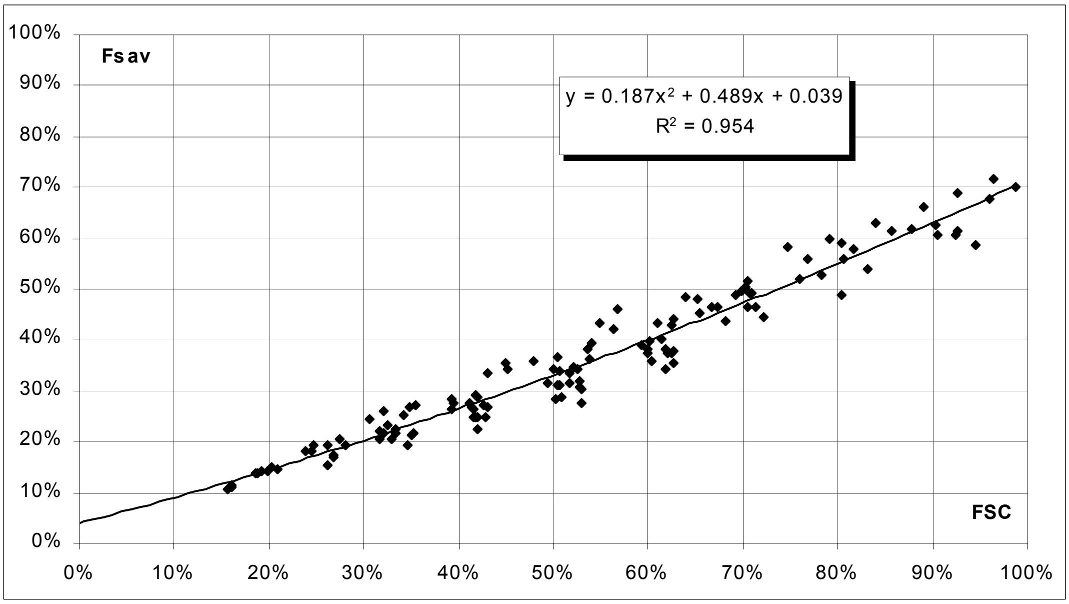


Diagram 7 : curve Fsav = f (FSC) for Direct Solar Floor

For the second one, we ontain the following curve :

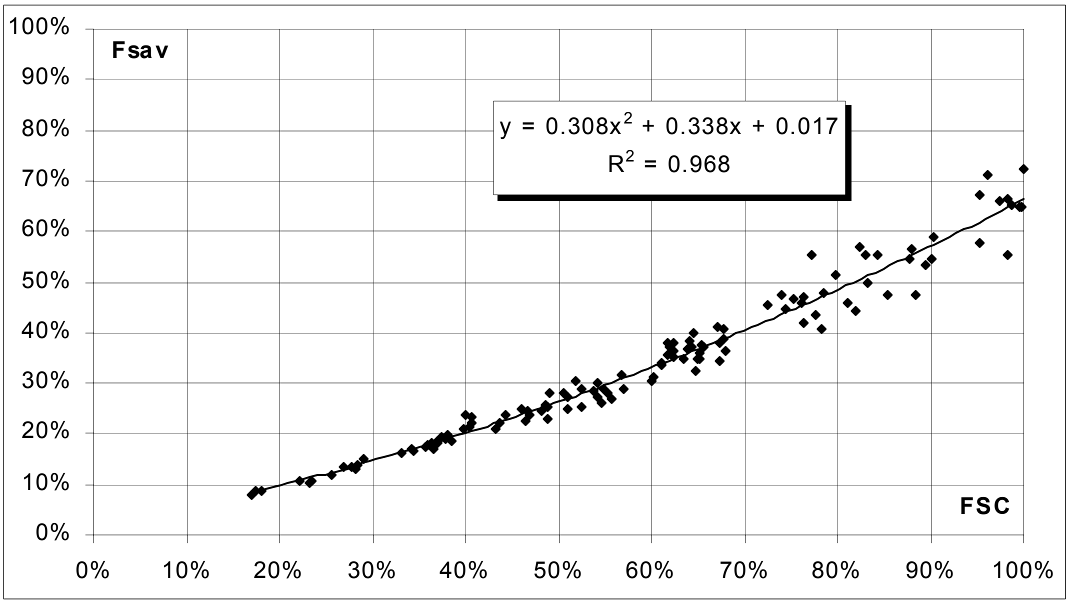


Diagram 8 : curve F_{sav} = f (FSC) for Tank in Tank

We can see more scattered points than in diagram 5, due to the broad range of DHW loads. Actually, performances of a combisystem are influenced by the ratio DHW load divided by total load. A small ratio is generally unfavourable, because the installation is oversized for summertime.

We have therefore extended the parabolic formula proposed for the fractional solar consumption, adding a corrective term, which takes into account the relative share of DHW load :

$$F_{sav} = (a + b \cdot FSC + c \cdot FSC^2) \cdot R_{DHW}^{\,d} \qquad (3)$$

where : R_{DHW} represents the ratio annual DHW load divided by annual total load (DHW and space heating).

Thus, it will be possible to characterise a combisystem with the three coefficients a, b, c of the parabola and with the corrective coefficient d.

For the first system, the expression, which gives the best fitting for F_{sav} is given hereunder :

$$F_{sav} = (0{,}043 + 0{,}659 \cdot FSC + 0{,}089 \cdot FSC^2) \cdot R_{DHW}^{\,0{,}1311} \qquad (4)$$

The determination coefficient has been calculated by comparing the values for F_{sav} obtained with simulations and with the correlation (4). It can be seen that the determination coefficient is improved by taking into account the corrective term related to the ratio R_{DHW}, and increases from 0,954 to 0,982.

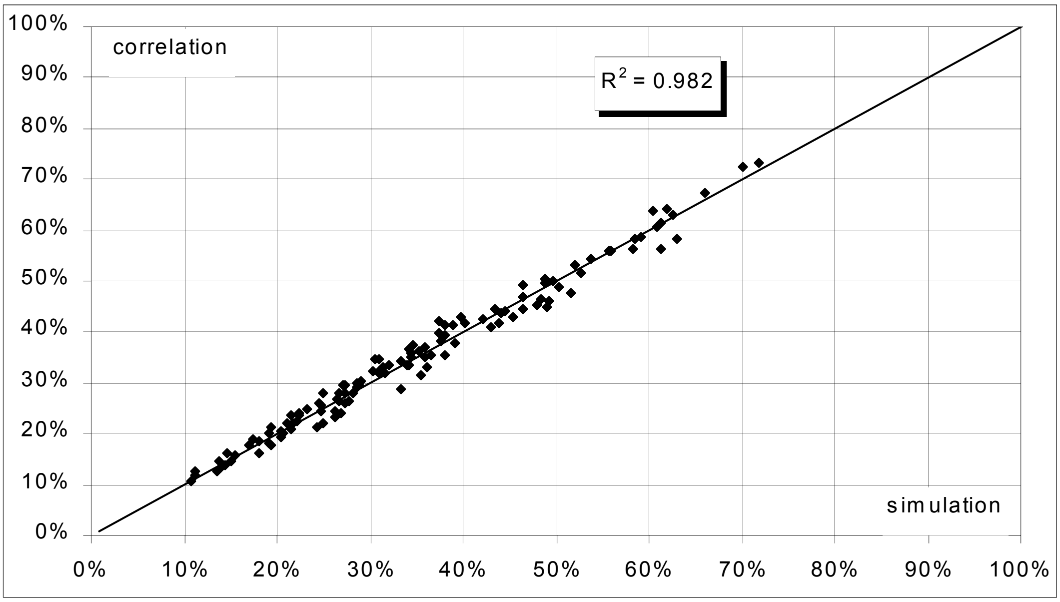


Diagram 9 : comparison between simulation and correlation for Direct Solar Floor

The following diagram shows how the representative surface for F_{sav} looks like :

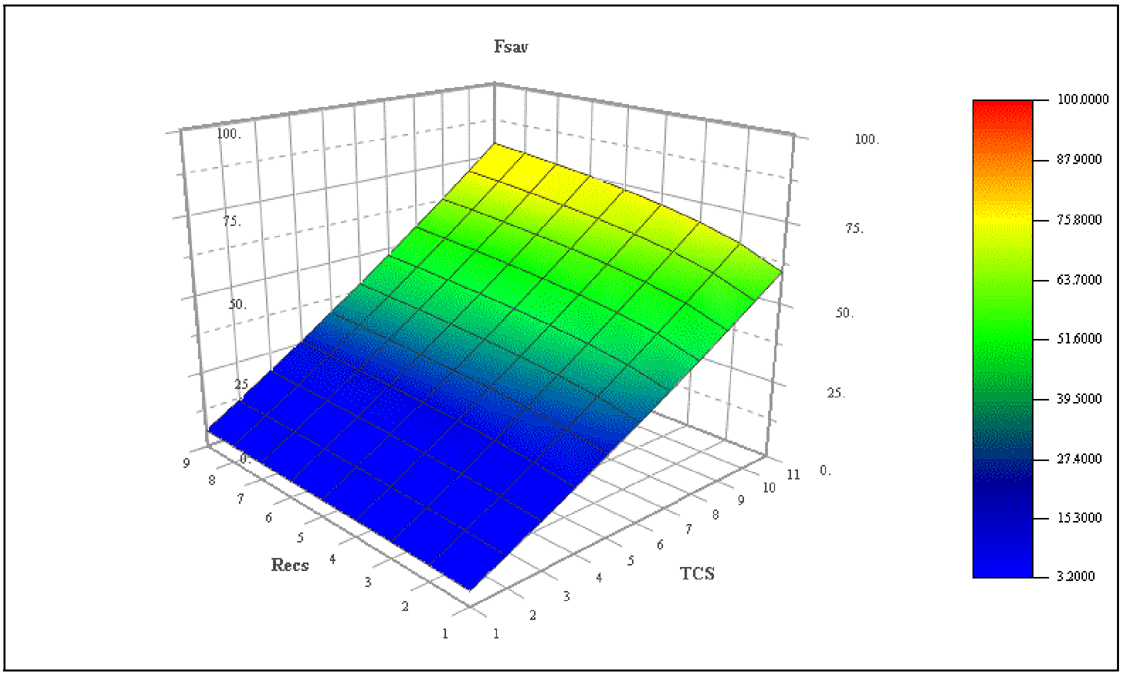


Diagram 10 : surface Fsav : f (FSC, RDHW) for Direct Solar Floor

For the second , the expression, which gives the best fitting for F_{sav} is given hereunder :

$$F_{sav} = (0{,}025 + 0{,}374 \,.\, FSC + 0{,}372 \,.\, FSC^2) \,.\, R_{DHW}^{\;0{,}0689} \qquad (5)$$

The determination coefficient has been calculated by comparing the values for F_{sav} obtained with simulations and with the correlation (5). For this system, influence of the ratio R_{DHW} seems to be less important, since the value for the exponent d is only 0,0689. Taking into account the corrective term related to the ratio R_{DHW} leads to an improvement of the correlation, however less important as in the previous case. The determination coefficient increases from 0,968 to 0,978.

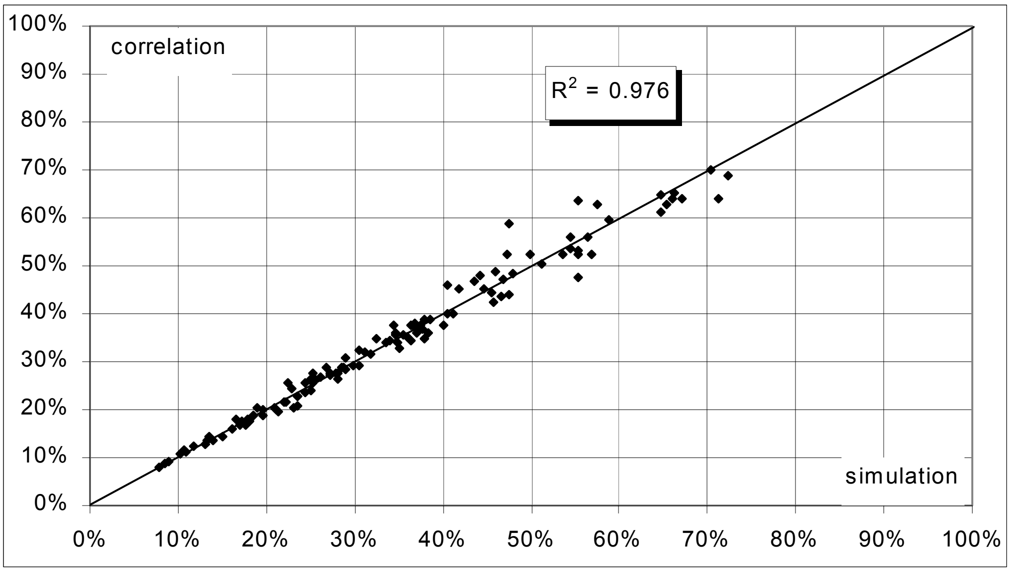


Diagram 11 : comparison between simulation and correlation for Tank in Tank

The following diagram shows how the representative surface for the second system looks like:

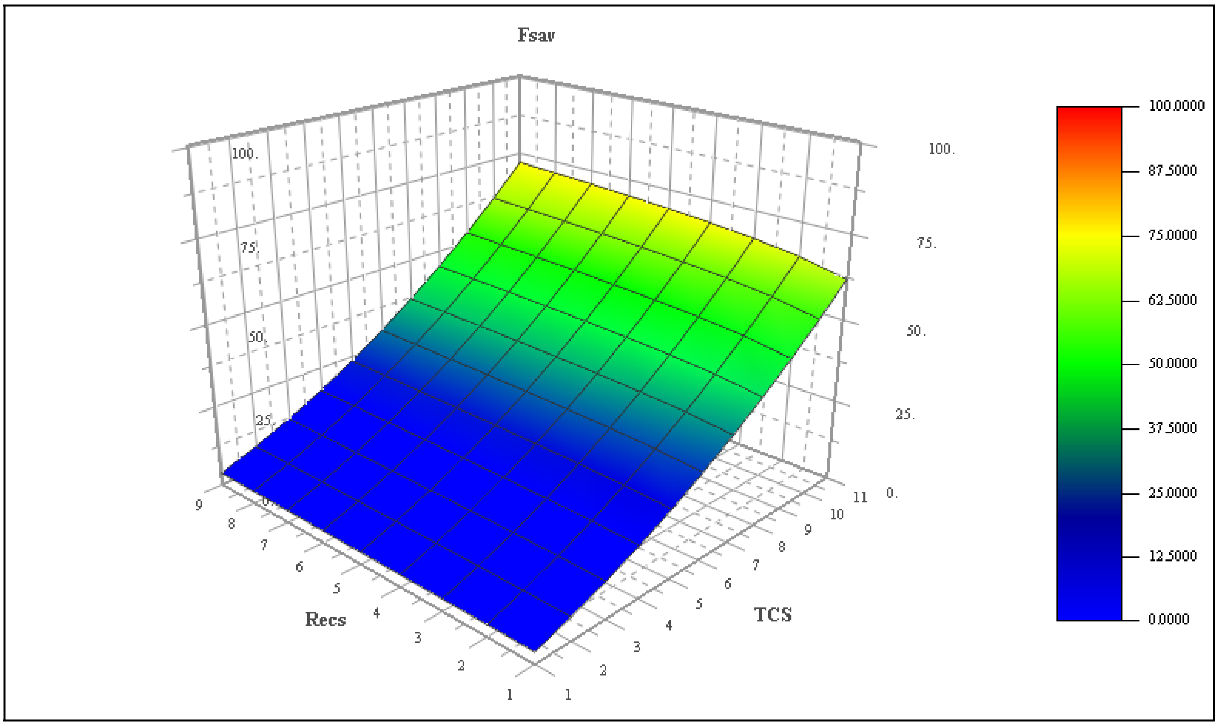


Diagram 12 : surface Fsav : f (FSC, RDHW) for Tank in Tank

We can conclude that this new method for the presentation of combisystems performances allows to synthesise in a single formula results obtained in very different working and dimensioning conditions. The surface F_{sav} = f (FSC, R_{DHW}) and the four coefficients of the corresponding equation characterise consequently a whole combisystem, with the solar collector, the auxiliary boiler and all the components like storage tanks, pipes, valves heat exchanger and the controller.

This new presentation fits as well for combisystems without storage for space heating as for those with a storage for space heating.

3 Use of this method for presentation of first results of simulations made in task 26

We have used the new method to present results obtained by simulation. For this approach, we made 27 simulations, with a TRNSED file developed by Philippe Papillon for system #3 [7] :

5. 3 climates : Stockholm, Zürich and Carpentras
6. 3 individual house (SFH 30, SFH 60 and SFH 100)
7. 3 solar collector sizes : 15, 20 and 30 m².

The following diagram shows the results obtained for the two first target functions defined in task 26 [8] : $F_{sav,therm}$ and $F_{sav,ext}$, using results for the reference cases computed by Philippe Papillon (space heating demand, final heat energy demand, primary energy demand, final electrical energy demand).

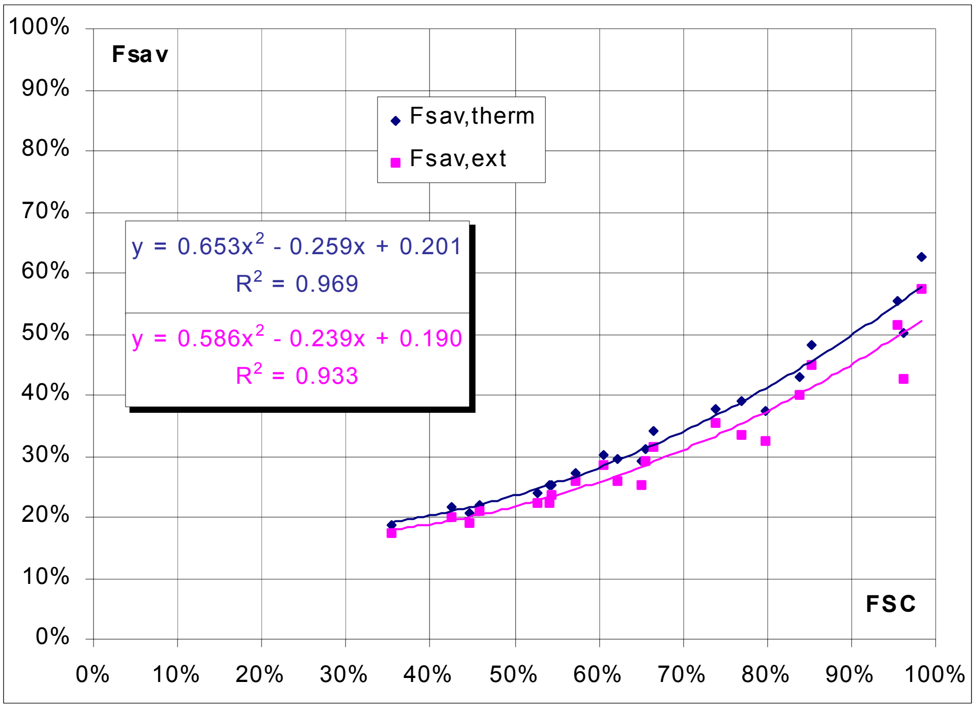


Diagram 13 : : curve Fsav = f (FSC) for Direct Solar Floor (simulations results)

If we try to use the four parameters formula (3), the determination coefficient can be increased from 0,969 to 0,970 for $F_{sav,therm}$ and from 0,933 to 0,937 for $F_{sav,ext}$.

So it appears that the method could be used to present results for different systems in the design handbook.

It must be pointed out that these results have been calculated using reference values computed by Philippe Papillon, that are different from those given in subtask C milestone report C 3.1 . This point has to be clarified before further use of the new method. Furthermore, the system simulated in this first try is not necessarily optimised.

4 Use of this method for presentation of experimental measurements

Results presented hereunder comes from the monitoring campaign, which has been undertaken between 1994 and 1999 in the framework of a Thermie project (SE 484/94 FR) [9] : 75 houses have been fitted out with Direct Solar Floors (n°3 of the coloured booklet [1]). 42 whole years of monitoring could be collected on 22 different houses. Thus, it is interesting to study if the approach presented above is relevant also for the characterisation of a combisystem from in situ measurements.

Features of realised houses vary in a great range:

- Floor area between **90 and 340 m²**
- Solar collector size between **12 and 36 m²**
- Various geographic locations : altitude between **10 and 1300 m**
- between **2 and 16** inhabitants.
- In some cases, swimming pool

Diagram 14 present experimental results with the common method : fractional energy savings related to the ratio irradiation on collector . collector area / SH load.

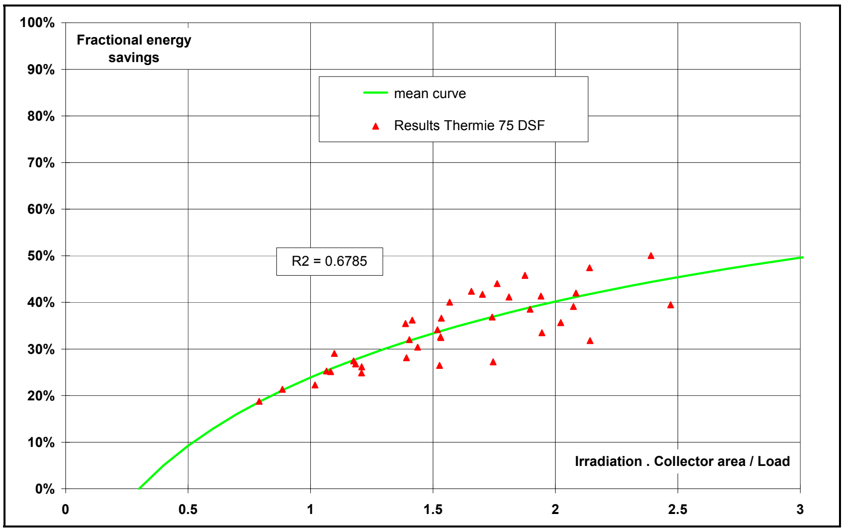


Diagram 14 : fractional energy savings related to the ratio irradiation on collector . collector area / SH for CLIPSOL combisystems

We can notice a relatively broad scattering of points with a determination coefficient far from 1. This is due to the wide range of DHW consumptions. Diagram 15 presents the same results related to the parameter FSC. Experimental points are more gathered than in diagram 14.

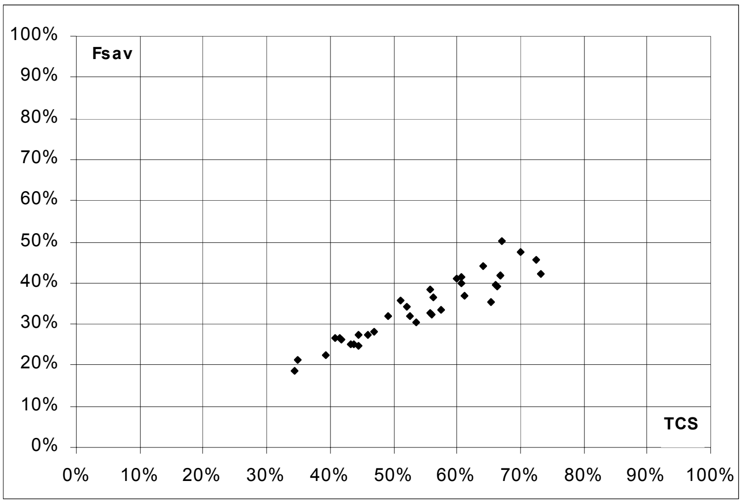


Diagram 15 : fractional energy savings related to parameter FSC for CLIPSOL combisystems used in the framework of SE 484/94 FR project

Correlation (3) leads to a better adjustment than diagram 15. The determination coefficient is reaching 0,867.

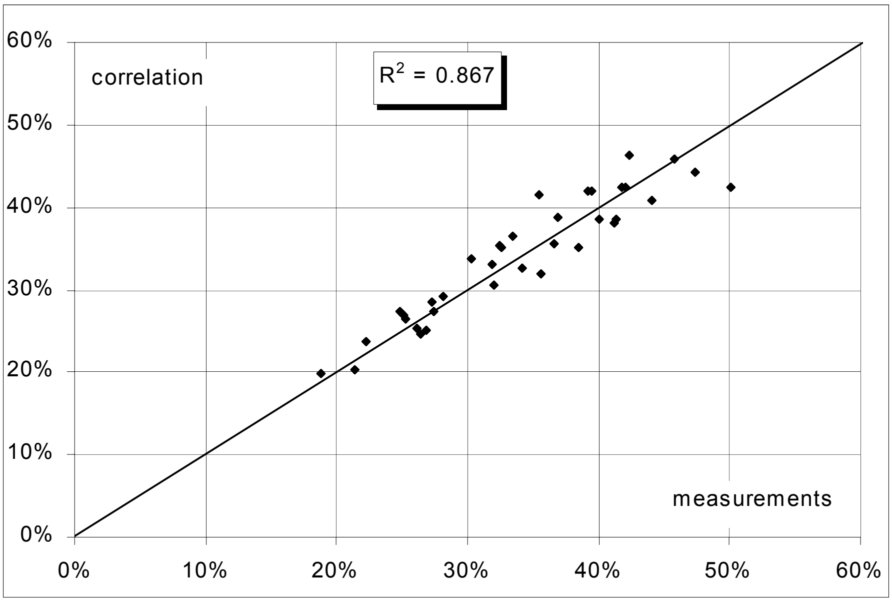


Diagram 16 : comparison between measurements and correlation for Direct Solar Floor

These diagrams show that the new method for the presentation of combisystems performances is relevant also for measurement results presentation.

5 Reference choice

In all examples presented above, calculations have been made with the PSD-MI method [4], in which energy consumptions for auxiliary and for the reference case are obtained either with efficiencies taken out the Th-C rules [6], or with the software Polysun [5]. However, it is clear that both coefficients F_{sav} et FSC are closely related to the way efficiencies and losses are calculated for both solar and reference systems.

Thus, in diagram 17, we have drawn the curve derivated from PSD-MI method, and the curve obtained with the same parameters, but using tank losses and boiler efficiency for the reference case defined in task 26 [3]. These parameters seem to be very optimistic (tank losses : 644 kWh/year, boiler efficiency : 85 %). This leads to very low reference consumptions, and consequently to a low fractional energy savings. When we compare two different combisystems, this distortion is not very important. On the contrary, if we want to give absolute figures characterising a system, the reference has to be chosen with the best accuracy possible.

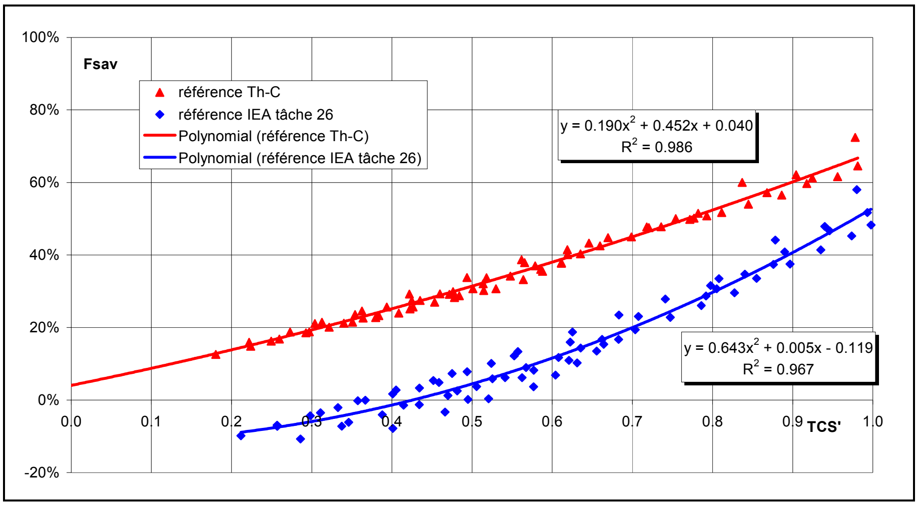


Diagram 17 : fraction energy savings related to FSC for two different references

It is therefore important to define very precisely the reference system, as well as the corresponding consumptions, so that the formula F_{sav} = f (FSC, R_{DHW}) is the most exact.

6 Conclusion : different ways to use the new method

The proposed formula $F_{sav} = (a + b . FSC + c . FSC^2) . R_{DHW}{}^{d}$ can be used in four different ways :

1. <u>For intercomparisons of combisystems from results obtained with simulations</u>

This is the work of task 26. As it has been decided to make simulations for all systems with the same solar collector, the same auxiliary boiler, the same DHW load, a diagram like the one in diagram 5 will be obtained, with a small scattering of the points for different climates and space heating loads. The curve obtained will be really a characteristic of the combisystem, independently of the solar collector or the auxiliary boiler. Obviously, if an auxiliary burner is integrated in the combistore, the characteristic curve will take into account its performances.

2. <u>For intercomparisons of combisystems from measuments obtained in a test rig</u>

The new method may be used also for presenting the results of tests made in several test facilities (SPF in Switzerland, TNO in the Netherlands, SERC in Sweden,CSTB in France,). Like above, the curve obtained will be really a characteristic of the combisystem, possibly with the auxiliary integrated burner, but independently of the solar collector.

3. <u>For in-situ monitoring results presentation and intercomparisons of combisystems</u>

In that case, the curve obtained will be more imprecise, for the reasons explained in paragraph 3. It will be really a characteristic of the whole combisystem, taking into account the solar collector and the auxiliary boiler or burner. Obviously, it will be more accurate if many points are used to calculate it. It should be possible to compare two different combisystems from a technical point of vue by examining the curves.

4. **<u>For simplified dimensioning methods, that can be used for example in regulation calculations</u>**

One can imagine to use a simplified approach, like the one presented in this paper, to develop a simplified calculation method, useful for example in regulation calculations.

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